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Evaluation of Nondestructive Assay/Nondestructive Examination Capabilities for Department of Energy Spent Nuclear Fuel

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EXECUTIVE SUMMARY

This report summarizes an evaluation of the potential use of nondestructive assay (NDA) and nondestructive examination (NDE) technologies on DOE spent nuclear fuel (SNF). It presents the NDA/NDE information necessary for the National Spent Nuclear Fuel Program (NSNFP) and the SNF storage sites to use when defining the role, if any, of NDA/NDE in characterization and certification processes. Note that the potential role for NDA/NDE includes confirmatory testing on a sampling basis and is not restricted to use as a primary, item-specific, data collection method. The evaluation does not attempt to serve as a basis for selecting systems for development or deployment. Although we used peer review to ensure the information is reasonable, caution should be used in applying the system-specific data since early performance predictions are not always met.

Information was collected on 27 systems being developed at eight DOE locations. This is not an exhaustive survey of systems across the entire DOE complex and does not include systems that may be available from the private sector. The survey does, however, present a good overview, which would not be changed significantly by a more exhaustive survey. The systems considered are developed to some degree, but are not ready for deployment on the full range of DOE SNF and still require additional development. The system development may only involve demonstrating performance on additional SNF, packaging the system for deployment, and developing calibration standards, or it may be as extensive as performing additional basic research. Development time is considered to range from one to four years.

We conclude that NDA/NDE systems are capable of playing a key role in the characterization and certification of DOE SNF, either as the primary data source or as a confirmatory test. NDA/NDE systems will be able to measure seven of the nine key SNF properties^a and to derive data for the two key properties not measured directly. The anticipated performance goals of these key properties are considered achievable except for enrichment measurements on fuels near 20% enrichment. Measurements can also be made for nearly all non-key SNF properties for which data may be required. However, these conclusions depend on the capabilities of one system. If this one system is excluded from consideration for any reason, then the remaining systems can only directly measure five of the nine key SNF properties, and, furthermore, require additional SNF information and/or more than ten calibration standards. If another specific system is disregarded, then only one of the ten key properties can be measured by NDA/NDE for all DOE SNF. The conclusions also depend on which of the SNF properties are considered essential. In order to provide data on all the SNF properties considered (a highly unlikely requirement), at least six systems would need to be deployed. NDA/NDE systems can likely be developed to measure the standard canisters now being considered for co-disposal of DOE SNF. This ability would allow the preparation of DOE SNF for storage now and the characterization and certification to be finalized later.

One of the most important contributions the NSNFP can make toward NDA/NDE deployment is to better define the characterization and certification requirements. Without well-defined requirements, there is significant risk that systems deployed may not meet all of the eventual requirements or may have unnecessary capability. Furthermore, some form of performance demonstration must be part of any system selection process to ensure that the system(s) selected will meet the performance requirements.

^a Key SNF properties as defined in this report are those properties that are important, for which quantitative limits can be postulated at this time, for which demonstration of DOE compliance is likely to be required, and for which this demonstration is not trivial.

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ACRONYMS

ANL-E	Argonne National Laboratory—East
ANL-W	Argonne National Laboratory—West
BOL	beginning-of-life (or pre-irradiation)
DOE	Department of Energy
DQO	Data Quality Objective
INEEL	Idaho National Engineering & Environmental Laboratory
LANL	Los Alamos National Laboratory
MTHM	metric tons of heavy metal (defined as plutonium, thorium, and uranium)
MTIHM	metric tons of initial (pre-irradiation) heavy metal (heavy metal is defined as plutonium, thorium, and uranium)
NDA/NDE	nondestructive assay / nondestructive examination
NSNFP	National Spent Nuclear Fuel Program
ORNL	Oak Ridge National Laboratory
PA	performance assessment
PNNL	Pacific Northwest National Laboratory
QA	Quality Assurance
RH-TRU	remote handled - transuranic waste
SFD	Spent Fuel Database
SNF	spent nuclear fuel
SNL	Sandia National Laboratory
SRS	Savannah River Site
WAC	waste acceptance criteria

1. INTRODUCTION

1.1 Background

The Department of Energy (DOE) spent nuclear fuel (SNF) characterization and certification process for transportation, storage, and geologic disposal is under development and is still uncertain. Whether nondestructive assay/nondestructive examination (NDA/NDE) systems have a role to play in this certification process depends upon the eventual answer to many questions, including the following:

- Which SNF properties will require data (e.g., is gross fissile adequate or is an isotopic breakdown on fissile also needed)?
- Will the requirement be to demonstrate that DOE SNF is below specified limits or must data be provided within a specified uncertainty?
- At what level must data be provided (e.g., DOE SNF totals, SNF group totals, reactor averages, or an item-specific level)?
- What level of confidence is required for certification?
- What is the quantity, quality, and pedigree of existing SNF data?
- Must the data be qualified, and, if so, how rigorous is the qualification process?
- To what extent can bounding approaches be used (e.g., assuming fuel is 100% enriched)?
- What are the relative costs for the options of qualifying existing data, obtaining new data, using less efficient packaging schemes, and SNF treatment?

Without the answers to these and other questions, it is not possible to either demonstrate or rule out the need for NDA/NDE systems, nor to determine whether their role will be as a primary data source or as a confirmatory test. However, because of the time required to develop and deploy these systems, and because of the need to place DOE SNF in canisters for interim storage soon, it is important to obtain general insights into the potential need and role of NDA/NDE technologies. This NDA/NDE Technology Evaluation Effort offers crucial information needed by the sites and the NSNFP to assess the potential role of NDA/NDE systems, based upon how the above questions are answered.

1.2 Purpose of This Report

The purpose of this report is to:

1. Identify the SNF properties for which at least one NDA/NDE technology is likely to be capable of providing data.
2. Identify the SNF properties for which NDA/NDE technologies are unlikely to be capable of providing data.
3. Present this information so that decision-makers can consider use of NDA/NDE systems in the characterization and certification process.

In addition, this effort provides NDA/NDE developers with insight into the SNF properties and performance requirements that may be needed for DOE SNF characterization and certification. This understanding allows NDA/NDE developers to give future consideration to additional methods of obtaining SNF measurements.

The purpose of this report is not to recommend whether NDA/NDE systems should be deployed or to suggest the extent to which they should be used. Furthermore, this report does not attempt to provide a basis for selection of individual systems for development or deployment.

2. PROCESS OVERVIEW

The overall process used for this task is presented in Figure 1.

The first step of the process was to identify candidate SNF properties for potential NDA/NDE use. Several documents (RW-0090, RW-0095, and DOE/SNF/REP-009) have differing lists of candidate properties for which data may be required in order to characterize and certify SNF for transportation, storage, or disposal, though disposal is their primary focus. The process used to develop this list of properties is described below.

- All candidate properties for which data may be required were identified. This was accomplished by combining the lists identified in RW-0090, RW-0095, and DOE/SNF/REP-009, and considering other properties that may be needed. When requirements from the different sources were the same, they were consolidated into one entry. When ambiguity existed on the similarity of requirements, separate entries were provided. The intent was to ensure that no data needs/requirements were overlooked, rather than to provide a rigorous crosswalk between the various data needs/requirements.

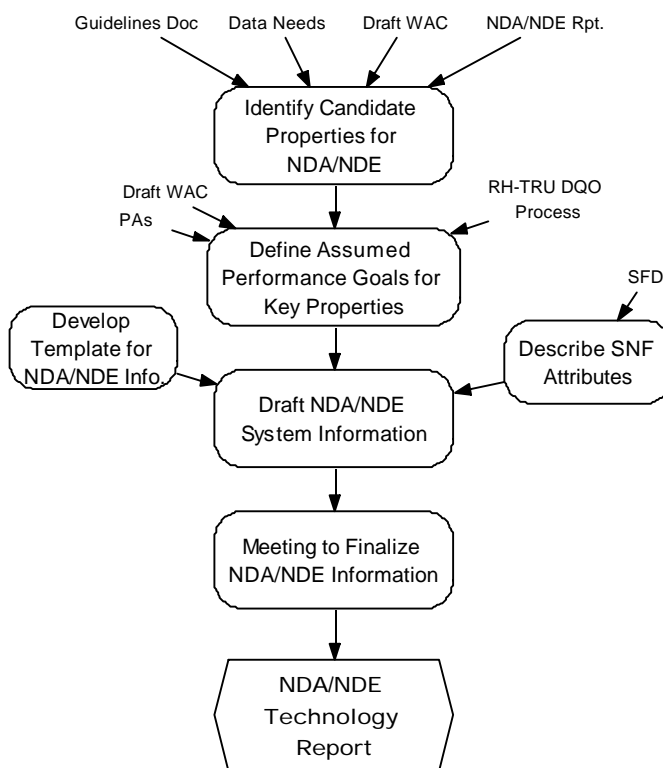


Figure 1. Process overview.

- Those properties for which NDA/NDE technologies cannot directly or indirectly provide data were deleted. DOE/SNF/REP-010 and NDA/NDE experts were used as the basis for identifying the properties for which NDA/NDE technologies can provide data. SNF properties related to the pre-irradiated state (e.g., beginning of life fissile loading) were deleted since the SNF is no longer in this condition and measurement of these SNF properties is not possible. Again, SNF properties were not deleted if a system could reasonably be developed to measure it.
- The next step was to identify assumed performance goals for NDA/NDE systems for the key properties. Key properties are those SNF properties that are expected to be of greatest importance to the NSNFP and the DOE sites in their process of developing characterization strategies. Key properties were defined by the following criteria:
 - Quantitative limits will be established for this property and it is possible to develop potential limits at this time. The limits may change, but there is reason to believe the limits will not be substantially more stringent than those predicted now.

- Some DOE SNF is close enough to the potential acceptance limit that SNF-specific data will likely be required to demonstrate compliance. If there is no potential for DOE SNF to exceed the limits, then it is possible that bounding approaches can be used in lieu of data.
- The process of obtaining the SNF data is not a trivial exercise. If there are readily available systems to obtain the necessary data within the uncertainties required, then addressing this SNF property in this evaluation is not of key importance.

Assumed performance goals were developed for the key properties to provide the developers with insight into the degree of performance that may be required. The assumed performance goals were based upon current draft acceptance criteria, performance analyses, and the best available SNF data. Information was also collected on NDA/NDE systems' ability to measure non-key properties, but assumed performance goals were not generally provided for those properties.

It was also necessary to describe the SNF that must be measured in order for the system developers to determine whether or not the assumed performance goals could be met. While a system may be able to measure some DOE SNF within the assumed performance goals stated, there may be some SNF attributes (for example size or radiation fields) that present limitations for the system. Rather than describe each attribute for each of the roughly 600 records in the Spent Fuel Database, it was more efficient to identify the range of values that exist for DOE SNF for each of the potentially limiting SNF attributes.

After developing the list of SNF properties, the assumed performance goals for the key properties, and the description of limiting SNF attributes, it was then possible to collect information on the ability of NDA/NDE systems to measure these properties. Because of the relational nature of the information, an Access database was developed to collect these data. The database was designed to provide the system developers with a limited number of predefined options to most questions. This simplified the data collection process and standardized the data collected. Ample text fields were also provided to allow the system developers to provide as much explanation as they deemed appropriate.

Meetings were held with the system developers to explain the purpose of the task, the operation of the database, and the intent of each data request. Data were collected from NDA/NDE personnel at ANL-W, ANL-E, Hanford (i.e., PNNL), INEEL, LANL, ORNL, SNL, and SRS. The system developers were then given copies of the database and asked to complete it for each system that they considered appropriate for DOE SNF. Generally, a system must have some degree of development completed to be considered. After data were received, they were reviewed for completeness and consistency. After collection, the data were distributed to everyone providing data for peer review. Comments were resolved between the reviewer and the author of the information whenever possible. A meeting was held on September 15 and 16, 1998 with NDA/NDE experts to resolve the few comments that could not be resolved between the reviewers and the authors.

3. RESULTS

3.1 Cautions on the Use of System Information

Historically, predictions on the capabilities of NDA/NDE systems have proven to be somewhat unreliable. The actual performance of a deployed system does not always prove to be as good as predicted, and sometimes there are limitations not previously envisioned. Therefore, though the data presented here have undergone peer review for reasonableness, the data on any specific system must be viewed with a degree of skepticism and should not be used as actual performance information. The actual performance that may be achieved by any system ultimately depends upon many factors, including the measurement duration, use of additional information or measurements, the number of calibration standards, measurement of bare fuel or canisters, neutron source fluence, etc. A performance demonstration that includes rigorous testing of measurement systems using cold mockups and irradiated materials is essential prior to the selection of specific systems for deployment.

While caution is in order, the overall nature of the data is not expected to change dramatically. The data provided on any specific system has a degree of uncertainty, but the overall conclusions are not expected to change due to refinement in any system-specific data.

3.2 Data Summary

Data were collected on 27 systems from eight DOE sites. This is not an exhaustive survey of all systems under development throughout the DOE complex or of systems offered in the private sector, but it does consider the systems that are most likely to meet the requirements. Table 1 summarizes the number of systems that have some measurement capability for each of the key SNF properties and an assessment of whether the assumed performance goals can be met. Appendix B presents over 100 pages of information on the systems, their capabilities, and their limitations.

This evaluation is based on the assumption that acceptance criteria may include fissile loading limits based upon enrichment (e.g., a potential maximum loading of 14.4 kg of fissile material for aluminum-clad SNF with enrichments of 20% or greater). There is a significant amount of SNF (over 200 canisters out of a total of roughly 3,000 canisters) with enrichments near 20%. Due to measurement uncertainty, it is not possible to demonstrate that SNF with an enrichment of about 19% is below the 20% criterion. The result would be a significant reduction in the loading of individual canisters and the generation of additional canisters. This could be a considerable cost penalty due to reduced packing efficiency and an increased number of canisters. Enrichment measurements for all other SNF is expected to meet the assumed performance goal.

There are no known systems that can measure I-129 or Tc-99 directly, as indicated in Table 1. However, numerous systems (at least 5) can measure a few radionuclides (e.g., cesium or europium) and derive the content of I-129, Tc-99, or any other radionuclide from them. The last date of irradiation can be derived in a similar manner. Depletion codes such as ORIGEN are used for such derivation calculations. Additional information such as reactor design and neutronics are also required as input to these depletion codes.

Table 1. Summary of NDA/NDE systems for key properties.

SNF Property	Assumed Performance Goal	Evaluated Performance	Number of Systems
Enrichment (% U-235)	Enrichment dependent (as low as 1% enrichment for SNF near 20% enrichment)	Meets goal except for SNF near 20% enrichment	3
Pu-239 content (weight % & g) (Post-Irradiation)	+/- 70%	Meets goal	14
Pu-241 content (weight % & g) (Post-Irradiation)	+/- 70%	Meets goal	1
Radionuclide Content: I-129	Factor of 3 to 10	Not Applicable	0
Radionuclide Content: Np-237	Factor of 3 to 10	Meets goal	1
Radionuclide Content: Tc-99	Factor of 3 to 10	Not Applicable	0
Total Fissile Material in Disposable Canister	+/- 70%	Meets goal	9
U-233 content, (Post-irradiation) (weight % & g)	+/- 70%	Meets goal	7
U-235 content, (Post-irradiation) (weight % & g)	+/- 70%	Meets goal	7

3.3 System Limitations

Table 1 presents an overview of the NDA/NDE measurement capability for each key property; however, it does not provide any perspective on the capabilities and limitations of systems measuring each property. For example, there may be many systems capable of measuring a specific SNF property, but they may be limited in the types of SNF they can measure. This is crucial information when considering the potential role of NDA/NDE. Table 2 presents a matrix summarizing the properties that each system is expected to be able to address and identifies the properties for which each system: (1) is not able to measure all DOE SNF, (2) requires additional information^a to measure the property, (3) requires 10 or more calibration standards, or (4) requires more than 60 minutes of measurement time.

3.4 Derived Information

This evaluation focuses on SNF properties that are measured without the need for external calculations such as depletion code calculations (e.g., ORIGEN). There are numerous ways in which a measurement can be used in conjunction with other data to perform external calculations to derive property information. As discussed previously, one notable example is the radionuclide content, which includes I-129 and Tc-99. Deriving such information is a common practice that is clearly possible for DOE SNF.

The potential for deriving property information is not addressed globally in this evaluation because there are too many potential combinations of measurements and additional information to reasonably be addressed. Furthermore, it is possible that all of the input data used for external

^a. Additional information includes reactor and/or fuel assembly information needed to perform the measurement.

Table 2. System-property summary matrix.

SNF Property	System Number (see following page for the cross-reference)																											Total
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	
Key Properties:																												
Enrichment (% U-235)			an										X						Xas									3
Pu-239	an		an	an	an			an	an				X			an	an	an	Xas	an	an					an		14
Pu-241													X															1
I-129																												0
Np-237													X															1
Tc-99																												0
Total fissile material	X		X										X	X		X			X	Xas		X				X		9
U-233	an		an										X			an			an	Xas						an		7
U-235	an		an										X			an			an	Xas						an		7
Non-Key Properties:																												
Activation products								X	X	X		X									X							5
Burnup (MWD/MTHM)	Xa		Xa					Xa	Xa	Xa	Xa	Xa	Xa	Xa		Xa	an	Xa	Xa	Xa	Xa					an		15
Canister thermal output		X																							an			2
Clad material																							X	X				2
Concentration and masses of absorbers																			Xas								X	2
Condition of fuel (intact, degraded, failed)						n																	X	X			X	4
Disposable canister leak rates												n																1
Free liquids in canister								Xat					X			X			Xas			X	X				X	7
Fuel compound (UO2, U-metal, etc.)																						X	X					2
Fuel dimensions (pellet and clad ID & OD)						n																X	X				X	4
Fuel rod pitch or plate spacing						n																X	X				X	4
Gross gamma flux								X	X	X	X	X	X							X	X							7
Gross neutron flux	X		X	X	X			X	X				X			X	X	X	X	X	X				X	X		15
Identification of control components																										X		1
k-eff			Xa													X										n		3
Last date of irradiation (YYYYMMDD)																												0
List of fission products and actinides								X*	X*	X*		X*									X*							5
Moisture content of fuel item								Xat					X			X			Xas									4
Moisture content of loaded canister								Xat					X			X			Xas									4
MTHM (Pu + Th + U)																												0
Number of SNF assemblies/items																							X	X				2
Organics								Xat																				1
Pu-238 & Pu-240	an		an	an	an			an	an				X			an	an	an	Xas	an	an					an		14
Requirements that canisters be sealed												n			nt								X	X				4
Th-232																												0
Thermal output for disposable canisters		X																								n		2
Total Pu	an		an	an	an			an	an				X			an	an	an	Xas	an	an					an		14
Total Th																												0
Total U			an										X						Xas									3
Type of SNF assembly - name																							X	X			X	3
U-232			Xat										X															2
U-234 and U-236													X															1
U-238			an										X						Xas									3
Number of Properties Addressed by the System	8	2	13	4	4	3	4	6	8	4	4	3	21	2	1	9	3	5	8	14	6	9	9	9	3	9	7	
Key to symbols																												
X - measures all SNF																												
a - requires additional data																												
n - not able to measure all SNF																												
s - requires 10 or more standards																												
t - time for measurement exceeds 1 hour																												
* - only a few radionuclides can be measure, the others must be derived																												

Table 2. System-property summary matrix (continued).

#	System Name	#	System Name
1	Active/Passive Neutron Coincidence Counter	15	Noble Gas Collection and Analysis
2	Calorimeter	16	Noise Analysis Measurement System
3	Delayed Neutron NDA	17	Nuclear Magnetic Resonance & Imaging
4	Directional Neutron Detector	18	Passive Neutron Detection
5	Dual-Slab Passive Neutron Counter	19	Research Reactor Fuel Counter
6	Fast Neutron Radiography	20	Resonance Transmission Analysis System
7	Fast Neutron Transmission Spectroscopy	21	Shielded Measurement System Phase 1
8	FORK	22	Shielded Measurement System Phase 2
9	Fork Plus (Advanced Fork)	23	SNF Digital Radiography Imaging System
10	Gamma Spectroscopy	24	Solid State SNF Radiographic Imaging
11	Gamma Spectroscopy CdZnTe or HPGe	25	Storage Canister Gas Activation
12	Low-level 90Sr Detector	26	Synchronous Active Neutron Detection
13	Multi-Detector Analysis System	27	Thermal & Epithermal Neutron Radiography
14	Neutron Activation/Gamma Detection		

calculations will need to be qualified, which may be difficult, expensive, and time consuming to accomplish. One of the primary reasons for considering the use of NDA/NDE is to avoid or minimize the need to qualify existing data.

3.5 Confirmatory Testing

One of the potential methods NUREG-1298 identifies for qualifying existing data is confirmatory testing. There may be considerable potential for using NDA/NDE in a confirmatory role rather than as a primary data source. Existing data and calculations could be used for characterization and certification. NDA/NDE measurements could then provide one or more pieces of new data to confirm the existing data. The extent to which confirmatory testing will be required is unknown at this time. If measurement of a few properties (e.g., total fissile content and abundance of a few specific radionuclides) will be adequate confirmation for all of the existing data, then NDA/NDE could be a very effective qualification method. If a measurement is required to confirm each piece of existing data, then it may be as effective to use NDA/NDE as the primary data source. As explained above, additional information on the certification requirements is needed before positions can be established.

3.6 Engineering Issues

The system information presented in this report is based upon the current state of system development with projections for what can reasonably be accomplished in the engineering process prior to deployment. There are numerous engineering topics that broadly apply to NDA/NDE systems. Several of these topics are addressed in the following paragraphs.

Deployment Environment. The environment in which each NDA/NDE system is envisioned to be deployed is presented in Appendix B. Roughly 2/3 of the systems are expected to be deployed in a dry environment, 1/4 are expected to be deployed in either a wet or dry environment, and only 10% are expected to be deployed in an underwater environment. However, with appropriate design, it is expected that nearly any system can be deployed in either a wet or a dry environment to meet the operational requirements.

Furthermore, deployment in a dry environment does not necessarily require use of a shielded dry cell. Three of the systems considered are envisioned to be deployed in a shielded ring configuration that mates to the bottom of a transfer cask. Many of the other systems could be deployed in a similar configuration if desired. The deployment environment is considered an engineering issue and is not generally a distinguishing feature of individual systems.

Measurement Duration. The measurement duration estimates presented in Appendix B are the developers' expectations of the way the system would be deployed. In about $\frac{3}{4}$ of the cases, the system's measurement uncertainty is improved by increasing measurement duration. The measurement duration is, therefore, inversely related to the uncertainty requirements imposed (i.e., longer measurements reduce the uncertainty of the measurement). Negotiation of larger acceptable uncertainties will result in lower measurement times. Note, however, that SNF handling activities are themselves time consuming, so reduction of measurement duration below a certain level may not significantly affect the overall time requirements.

Neutron Sources. The active neutron systems' measurement duration and uncertainty highly depend upon the fluence of the neutron source used. Several efforts are underway across the DOE complex to develop a higher fluence neutron source. An example is the High Fluence Neutron Source, which uses a fusion technique. The development of a high fluence neutron source will improve the performance of several NDA/NDE systems.

Canister Size. An indication of each system's ability to measure both bare and canistered SNF is provided in Appendix B. In general, the underlying physics do not prevent systems from being able to measure the standard canisters (18-inch or 24-inch diameter, 10-foot or 15-foot-long canisters) currently being proposed by the NSNFP. In fact, at least three systems are being developed to measure such canisters. The measurement of SNF in standard canisters is desirable because SNF could be loaded now and measurements taken any time prior to shipment. In addition, it would take less time to measure roughly 3,000 canisters than 200,000 individual fuel items.

However, measurement of large canisters inherently results in some increase in uncertainty and longer measurement times. Computer modeling or measurements, or both, are necessary to confirm that the performance requirements can be met.

Uncertainty. Numerous engineering-related factors affect the measurement uncertainty including measurement duration, neutron source fluence, canister size, number of calibration standards, number of detectors, and type of detectors. It is difficult to project measurement uncertainties at this time because these factors are unresolved. The engineering process can be used to keep the measurement uncertainty to the required levels.

4. CONCLUSIONS

The results presented in Section 3 can be summarized as follows:

- One or more systems could measure seven of the nine key properties (i.e., U-233, U-235, Pu-239, Pu-241, and Np-237 content, total fissile material in disposal canisters, and enrichment) for all DOE SNF.
- The assumed performance goals are considered achievable for each of the seven key properties that can be measured except for enrichment. SNF with enrichments of about 19% cannot be demonstrated to be below 20% by NDA/NDE systems. Effort should be made to negotiate data needs for enrichment into ranges that allow less stringent performance goals.
- There are no systems that can measure the key properties of I-129 or Tc-99 content directly. However, this information can be derived from depletion code calculations (e.g., ORIGEN calculations) using measurements of other radionuclides as inputs.
- One or more systems could measure each of the non-key properties except last date of irradiation, Th-232, total thorium content, and MTHM. These non-key properties can be derived from other information.
- For about two-thirds of the system-property measurements,^a the system could perform measurements on all SNF without limitations.
- For about half of the system-property measurements, additional information (e.g., burnup or enrichment of the fuel item) is required in order to perform the measurement. The need for additional information requires collection and potential qualification of additional data.
- No single system can measure all key and non-key properties. Therefore, it may be necessary to deploy more than one NDA/NDE system, depending upon the properties that may require NDA/NDE measurements.
- There is a broad variation in maturity of the various systems. For most properties, the level of maturity ranges from existing field deployment to no experience. Virtually all systems will require some degree of R&D or packaging before deployment, which is expected to require less than 1 year to 4 years.
- The majority of systems (19 of 27) are expected to be usable for either bare or canistered SNF. Several of the systems are designed to measure standard canisters (i.e., canisters 18-inch or 24-inch diameter canisters 10 or 15 feet long). Measuring these large standard canisters is theoretically feasible for most systems, but there may be some degradation in uncertainties, and it would present engineering challenges for some systems.
- In general, the systems can be designed for use in either a wet or a dry environment. Furthermore, many systems could be designed with an integral shield ring that does not require a shielded cell.

^a. The term system-property measurement is used to designate each cell of Table 2 for which there is measurement capability.

- The duration of measurements ranges from 1 minute to 480 minutes. Most (roughly 90%) of the system measurements are performed in no more than 60 minutes.

It appears there are potential NDA/NDE capabilities to meet virtually any characterization need, but that these capabilities still require significant development. There are systems or sets of systems that can provide data for nearly any SNF property or set of SNF properties that may be required. The ultimate acceptance criteria are obviously not known at this time, but it appears that the systems will be able to meet these requirements.

The above conclusions are based upon system information containing significant uncertainties, since system performance has not been demonstrated across the spectrum of DOE SNF for any system. Therefore, it is appropriate that we consider the sensitivity of these conclusions to the system information provided or the systems considered.

The conclusions can be sensitive to the systems included in the evaluation. If system 13 (Multi-Detector Analysis System, which consists of a suite of multiple technologies) is excluded from consideration for any reason, then a primary conclusion needs to be altered: the remaining systems can only provide direct measurements on five of the nine key SNF properties and, furthermore, require additional SNF information and/or more than 10 calibration standards. The key properties that cannot be measured are Pu-241, Np-237, I-129 and Tc-99 content, and enrichment for some SNF. Note that it might be possible to derive these properties from the measurements taken plus additional information. Furthermore, exclusion of system 20 (Resonance Transmission Analysis System) results in only one of the ten key properties, namely total fissile content in the disposal canister, being measured for all DOE SNF. Exclusion of other systems does not alter the conclusions significantly.

While it may be likely that NDA/NDE systems can be developed to meet the requirements, it is also important to recognize that using NDA/NDE is not a perfect and simple solution. For example, it would take six or more systems to provide data on all SNF properties. Additionally, some of the systems would require more information (e.g., pre-irradiation data) and may not be able to perform the measurements on all DOE SNF. Clearly, it is inappropriate to make deployment decisions until it becomes obvious that the measurements are needed. On the other hand, schedules for preparing DOE SNF may not permit waiting until the acceptance criteria are known. Therefore, it is important for a best estimate of the acceptance criteria to be developed in the near term and efforts made to ensure that system development is underway to meet these potential characterization and certification needs.

5. RECOMMENDATIONS FOR FUTURE ACTIVITIES

The recommendations presented in NSNFP report “NDA/NDE Resolution Team Meeting Report” [DOE/SNF/REP-010, section 6.2] are still appropriate. These and other recommended actions are summarized below in roughly sequential order:

- Identify Data Needs—This report provides a list of potential data needs for the purpose of collecting NDA/NDE system information, but it does not attempt to predict the data needs that will ultimately be imposed and does not go beyond properties that NDA/NDE can potentially address. It is crucial to determine the minimum but sufficient set of data needed for characterization and certification before making NDA/NDE deployment decisions. This process is likely to require multiple iterations until disposal.
- Establish Data Quality Objectives—It is also important to determine the allowable uncertainty and confidence level for each data need. These Data Quality Objectives will take time to develop and are likely to be revised several times, but it is important to begin this process.
- Define the Role of NDA/NDE—The NSNFP and sites must determine the role of NDA/NDE, for what properties it will be used, whether it will be used as a primary data source or a confirmatory source, and on which SNF it will be used.
- Establish NDA/NDE Performance Requirements—The above items can be translated into a set of operational performance requirements for NDA/NDE systems. System developers will then have a more clearly defined goal at which to aim.
- Initiate Collaborative Development—It is likely that collaboration will be required to achieve an optimal system. This collaboration may consist of using concepts, equipment, facilities, and expertise from several sites. Examples of areas for collaboration include using facilities for testing or using neutron sources developed by others.
- Performance Demonstration—Before committing to deployment of any system, it is essential to demonstrate its capability. It may not be necessary to demonstrate capability for all SNF, but a demonstration is needed across a reasonable range of SNF with varying attributes (enrichment, burnup, configuration, composition, etc.). Any performance demonstration should be performed under realistic conditions to reflect radiation fields, sizes, and compositions of the SNF that will ultimately be measured.

6. REFERENCES

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- DOE/SNF/REP-009 “Guidelines for Meeting Repository Requirements for Disposal of US Department of Energy Spent Nuclear Fuel (Draft),” DOE/SNF/REP-009, J A Dearien, September 1997.
- DOE/SNF/REP-010 “Non-Destructive Assay / Non-Destructive Examination Resolution Team Meeting Report,” DOE/SNF/REP-010, June 1997.
- EPA QA/G-4 “Guidance for Planning for Data Collection in Support of Environmental Decision Making Using the Data Quality Objectives Process,” EPA QA/G-4, Interim Final, October 6, 1993.
- NUREG-1298 “Qualification of Existing Data for High-Level Nuclear Waste Repositories - Generic Technical Position,” NUREG-1298, W. D. Altman, J. P. Donnelly, and J. E. Kennedy, February, 1988.
- RW-0090 “OCRWM Data Needs for DOE Spent Nuclear Fuel,” A00000000-01717-2200-0090 Rev 02, February 1998.
- RW-0095 “Mined Geologic Disposal System Waste Acceptance Criteria,” B00000000-01717-4600-0095 Rev 00, September 1997.
- RW-0108 “Mined Geologic Disposal System Draft Disposability Interface Specification,” B00000000-01717-4600-00108 REV 01, Draft A, unsigned draft, June 1998.
- RW-0333P “Quality Assurance Requirements Description,” RW-0333P, Rev 4, August 4, 1995.

Appendix A

Glossary

GLOSSARY

Canister	A thin-walled, unshielded metal container used to hold fuel assemblies. Canisters are used in combination with specialized “overpacks” that provide shielding and structural support for transportation or storage purposes. (Overpacks are sometimes referred to as casks.) [DOE/EIS-0251]
Certification	<p>The act of determining, verifying, and attesting in writing to the achievement or compliance with specified requirements [RW-0333P]</p> <p>The process of documenting and verifying that the state of the fuel, as determined through the characterization process, meets requirements for disposition into a national repository [DOE/SNF/REP-009]</p>
Characterization	<p>The determination of waste composition and properties, whether by review of process knowledge, nondestructive examination or assay, or sampling and analysis, generally done for the purpose of determining appropriate storage, treatment, handling, transport, and disposal requirements [SNF & INEL EIS]</p> <p>The activity associated with gathering or production of data which define the fuel. These characterization parameters include physical data such as pedigree, weight, dimensions, material content, etc. [DOE/SNF/REP-009]</p>
Confidence	The chance or likelihood that a specified value is part of the population (if a specific value lies outside \pm three standard deviations from the mean, then we have a 99.7% confidence that this observation is different from the population since 99.7% of the population lies in that range) [DOE/EH-0186]
Confirmatory Testing	<p>An evaluation subject to implementing documents that investigates the properties of interest of data in an attempt to confirm the quality of the data [RW-0333P]</p> <p>Testing conducted under a 10 CFR 60, Subpart G QA program which investigates the properties of interest (e.g., physical, chemical, radiological, mechanical) of an existing data base [NUREG-1298]</p>
Data Quality Objective (DQO)	Qualitative and quantitative statements derived from the DQO process that clarify study objectives, define the appropriate type of data, and specify the tolerable levels of potential decision errors that will be used as the basis for establishing the quality and quantity of data needed to support decisions. [EPA QA/G-4]
Existing Data	Data developed prior to the implementation of a quality assurance program that meets OCRWM requirements and data that are not information accepted by the scientific and engineering community as established fact [RW-0333P]

Key Property	<p>These are SNF properties that are expected to be of greatest importance to the NSNFP and the DOE sites. Key properties must meet the following criteria:</p> <ul style="list-style-type: none"> • It is expected that limits on this property will be included in the final WAC. Obviously, it is not a key property if it is likely that a property will be deleted from the final WAC. • Quantitative limits will be established for this property and it is possible to develop potential limits at this time. If it is not possible to project a limit for a property, then it is not possible to determine the adequacy of any class of NDA/NDE systems. The limits may change, but there is reason to believe the limits will not be substantially more stringent than those predicted now. • Some DOE SNF is close enough to the limit that SNF-specific data will likely be required to demonstrate compliance. If there is no potential for DOE SNF to exceed the limits, then it is possible that bounding approaches can be used in lieu of data. • The process of obtaining the data is not a trivial exercise. If there are readily available systems to obtain the necessary data within the uncertainties required, then addressing this property in this evaluation is not of key importance.
Limits	The values of a quantity that must not be exceeded [DOE/EH-0186] SNF which can be demonstrated to meet the limits established for a property is acceptable for disposal by virtue of that compliance
Nondestructive Assay (NDA)	The quantitative non-destructive and non-intrusive assay/characterization of the intrinsic material characteristics of SNF, such as quantitative analysis of composition, fissile material content, and radionuclide content [DOE/SNF/REP-010, Rev 0]
Nondestructive Examination/ Evaluation (NDE)	The non-intrusive examination/evaluation of the extrinsic characteristics of SNF, such as the configuration or gross structure of the SNF, extent of corrosion, size/dimensions, and water intrusion into a package [DOE/SNF/REP-010, Rev 0]
Property	A distinguishing characteristic or feature As used here, it is a characteristic (eg, dimensions, weights, etc) for which qualified data must be obtained.
Qualified Data	Data initially collected under a 10 CFR 60, Subpart G quality assurance (QA) program, or existing data qualified in accordance with this GTP [NUREG 1298]
Uncertainty	A measure of the total variability associated with sampling and measurement that includes the two major error components, systematic error (bias) and random error (imprecision) [EPA QA/G-4]

Waste Package

The disposal overpack and its contents. In the case of DOE SNF, the contents may include one or more canisters

Appendix B
NDA/NDE System Reports

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System Report

System Name:

Description:

SNF Experience:

Description of SNF Experience:

Non-SNF Experience:

Description of Non-SNF Experience:

Funded Development:

Operating Environment:

R and D Costs:

Procurement Costs:

In-Cell Space:

Out-Cell Space:

O and M Personnel:

R and D Schedule:

Deployment Schedule:

Measurable Configurations:

Additional Information:

Active/Passive Neutron Coincidence Counter

This system detects neutrons and counts neutron coincidences.

Field Deployed for Single SNF/Non-SNF.

This system has been used for MTR fuel at Savannah River Site. A similar system will be field deployed for measurement of BN-350 fast breeder reactor spent fuel in the 4th quarter CY 1998.

Field Deployed for Multiple SNF/Non-SNF.

Neutron coincidence counting is the standard for measuring fissile material.

This system is essentially developed. The only future development would be tailoring detectors to specific spent fuel configurations.

Underwater and Dry Cell.

\$200K to \$1M

\$200K to \$1M

10 to 50 sq. ft.

10 to 50 sq. ft.

<1 FTE

<1 yr

<1 yr

Bare Fuel and Canisters

R&D costs are expected to be \$200k, Procurement Costs are expected to be \$200k to \$700k, InCell and OutCell Space are each expected to be 16 ft².

SNF Property # 1

Performance Goal:

Meets Performance Goal:

Phenomena Measured:

Additional Information Required:

Pu-239 content (weight % & g) (Post-Irradiation)

Key Property: +/- 70%

Yes

Coincident neutrons.

BOL Enrichment

Burnup

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:

Measurement Duration:

Sensitivity to Measurement Duration:

Calibration Standards Required:

Property Measurement Comments:

5%

5 min.

Uncertainty is improved by increasing measurement duration.

<10 Standards.

Additional information on the fuel geometry is also required.

This system can be run actively and passively. In active mode it determines total fissile content. If combined with gamma-ray isotopics, then Pu-239 can be determined. It is expected that 10 calibration standards may be required.

Limiting SNF Attribute # 1 Container wet/dry
Attribute Value: Contents partially or fully flooded
Limiting Attribute Comment:
Limiting SNF Attribute # 2 Fuel unit poison material
Attribute Value: Boron
Attribute Value: Cadmium
Attribute Value: Erbium
Attribute Value: Gadolinium
Limiting Attribute Comment:
Limiting SNF Attribute # 3 Fuel unit/container height/width
Attribute Value: 50 cm to <127 cm
Limiting Attribute Comment:
Limiting SNF Attribute # 4 Gross neutron radiation (based on PWR assembly)
Attribute Value: 1E+04 to 1E+06 neutron/assy/sec
Attribute Value: 1E+06 to 1E+08 neutron/assy/sec
Attribute Value: >1E+08 neutron/assy/sec
Limiting Attribute Comment:

SNF Property # 2 Total Fissile Material in Disposable Canister
Performance Goal: Key Property: +/- 70%
Meets Performance Goal: Yes
Phenomena Measured: Coincident neutrons.
Additional Information Required: None

Measurement Uncertainty: 5%
Measurement Duration: 5 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: No additional information on the fuel geometry is required to give total fissile mass (U-235 equivalent).

 This system can be run actively and passively. In active mode it determines total fissile content. If combined with gamma-ray isotopics, then Pu-239 can be determined. It is expected that 10 calibration standards may be required.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 3	U-233 content, (Post-irradiation) (weight % & g)
Performance Goal:	Key Property: +/- 70%
Meets Performance Goal:	Yes
Phenomena Measured:	Coincident neutrons.
Additional Information Required:	BOL Enrichment
	Burnup Other (Identified in Property Measurement Comments)
Measurement Uncertainty:	5%
Measurement Duration:	5 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Additional information on gamma ray isotopics is also required.
Limiting SNF Attribute # 1	Container wet/dry
Attribute Value:	Contents partially or fully flooded
Limiting Attribute Comment:	
Limiting SNF Attribute # 2	Fuel unit poison material
Attribute Value:	Boron
Attribute Value:	Cadmium
Attribute Value:	Erbium
Attribute Value:	Gadolinium
Limiting Attribute Comment:	
Limiting SNF Attribute # 3	Fuel unit/container height/width
Attribute Value:	50 cm to <127 cm
Limiting Attribute Comment:	
Limiting SNF Attribute # 4	Gross neutron radiation (based on PWR assembly)
Attribute Value:	1E+04 to 1E+06 neutron/assy/sec
Attribute Value:	1E+06 to 1E+08 neutron/assy/sec
Attribute Value:	>1E+08 neutron/assy/sec
Limiting Attribute Comment:	
SNF Property # 4	U-235 content, (Post-irradiation) (weight % & g)
Performance Goal:	Key Property: +/- 70%
Meets Performance Goal:	Yes
Phenomena Measured:	Coincident neutrons.
Additional Information Required:	BOL Enrichment
	Burnup Other (Identified in Property Measurement Comments)
Measurement Uncertainty:	5%
Measurement Duration:	5 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Additional information on gamma ray isotopics is also required.

Limiting SNF Attribute # 1 Container wet/dry
Attribute Value: Contents partially or fully flooded
Limiting Attribute Comment:
Limiting SNF Attribute # 2 Fuel unit poison material
Attribute Value: Boron
Attribute Value: Cadmium
Attribute Value: Erbium
Attribute Value: Gadolinium
Limiting Attribute Comment:
Limiting SNF Attribute # 3 Fuel unit/container height/width
Attribute Value: 50 cm to <127 cm
Limiting Attribute Comment:
Limiting SNF Attribute # 4 Gross neutron radiation (based on PWR assembly)
Attribute Value: 1E+04 to 1E+06 neutron/assy/sec
Attribute Value: 1E+06 to 1E+08 neutron/assy/sec
Attribute Value: >1E+08 neutron/assy/sec
Limiting Attribute Comment:

SNF Property # 5 Total Pu content (post-irradiation) (g)
Performance Goal: +/- 70%
Meets Performance Goal: Yes
Phenomena Measured: Coincident neutrons.
Additional Information Required: BOL Enrichment
Burnup Other (Identified in Property Measurement Comments)

Measurement Uncertainty: 5%
Measurement Duration: 5 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: Gamma ray isotopics
Limiting SNF Attribute # 1 Container wet/dry
Attribute Value: Contents partially or fully flooded
Limiting Attribute Comment:
Limiting SNF Attribute # 2 Fuel unit poison material
Attribute Value: Boron
Attribute Value: Cadmium
Attribute Value: Erbium
Attribute Value: Gadolinium
Limiting Attribute Comment:
Limiting SNF Attribute # 3 Fuel unit/container height/width
Attribute Value: 50 cm to <127 cm
Limiting Attribute Comment:
Limiting SNF Attribute # 4 Gross neutron radiation (based on PWR assembly)
Attribute Value: 1E+04 to 1E+06 neutron/assy/sec
Attribute Value: 1E+06 to 1E+08 neutron/assy/sec
Attribute Value: >1E+08 neutron/assy/sec
Limiting Attribute Comment:

SNF Property # 6	Burnup (MWD/MTHM)	
Performance Goal:	+/- Factor of 3 to 10	
Meets Performance Goal:	Yes	
Phenomena Measured:	Coincident neutrons.	
Additional Information Required:		BOL Enrichment BOL Fissile Content
Measurement Uncertainty:	5%	
Measurement Duration:	5 min.	
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.	
Calibration Standards Required:	<10 Standards.	
Property Measurement Comments:		
SNF Property # 7	Gross neutron flux	
Performance Goal:	No specific limit at this time.	
Meets Performance Goal:	Yes	
Phenomena Measured:	Coincident neutrons.	
Additional Information Required:	None	
Measurement Uncertainty:	5%	
Measurement Duration:	5 min.	
Sensitivity to Measurement Duration:	Uncertainty is not improved by increasing measurement duration.	
Calibration Standards Required:	<10 Standards.	
Property Measurement Comments:		
Limiting SNF Attribute # 1	No Limitation	
Attribute Value:	No Limitation	
Limiting Attribute Comment:		
SNF Property # 8	Pu-238 & Pu-240 content (weight %) (Post-Irradiation)	
Performance Goal:	No specific limit at this time.	
Meets Performance Goal:	Yes	
Phenomena Measured:	Coincident neutrons.	
Additional Information Required:		BOL Enrichment
	Burnup	Other (Identified in Property Measurement Comments)
Measurement Uncertainty:	5%	
Measurement Duration:	5 min.	
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.	
Calibration Standards Required:	<10 Standards.	
Property Measurement Comments:	Gamma ray isotopics	

Limiting SNF Attribute # 1 Container wet/dry
Attribute Value: Contents partially or fully flooded
Limiting Attribute Comment:
Limiting SNF Attribute # 2 Fuel unit poison material
Attribute Value: Boron
Attribute Value: Cadmium
Attribute Value: Erbium
Attribute Value: Gadolinium
Limiting Attribute Comment:
Limiting SNF Attribute # 3 Fuel unit/container height/width
Attribute Value: 50 cm to <127 cm
Limiting Attribute Comment:
Limiting SNF Attribute # 4 Gross neutron radiation (based on PWR assembly)
Attribute Value: 1E+04 to 1E+06 neutron/assy/sec
Attribute Value: 1E+06 to 1E+08 neutron/assy/sec
Attribute Value: >1E+08 neutron/assy/sec
Limiting Attribute Comment:

System Report

System Name:**Description:****Calorimeter**

The calorimeter measures the heat generated by any item placed inside it. There are several types available. The Constant Temperature Servo-Control Method uses a controlled heat loss enclosure plus heaters to maintain a constant temperature. The energy required for heating plus the heat generated by the item placed inside the enclosure are then fixed by the heat removal rate. The heat generation rate of the item being measured can be determined by the electrical heating rate.

SNF Experience:**Description of SNF Experience:****Non-SNF Experience:****Description of Non-SNF Experience:****Funded Development:****Operating Environment:****R and D Costs:****Procurement Costs:****In-Cell Space:****Out-Cell Space:****O and M Personnel:****R and D Schedule:****Deployment Schedule:****Measurable Configurations:****Additional Information:**

None.

The extent of application to SNF is not known.

Field Deployed for Multiple SNF/Non-SNF.

This technique is well established and is available commercially.

None required except engineering for deployment.

Dry Cell.

<\$200K

\$200K to \$1M

10 to 50 sq. ft.

10 to 50 sq. ft.

<1 FTE

None

<1 yr

Bare Fuel and Canisters

SNF Property # 1**Performance Goal:****Meets Performance Goal:****Phenomena Measured:**

Disposable Multi-Element Canister Thermal Output

No specific limit at this time.

Yes

For the Constant Temperature Servo-Control Method, the electrical current flowing into the Calorimeter is measured and the heat generated by the item being measured can be calculated directly.

Additional Information Required:

None

Measurement Uncertainty:**Measurement Duration:****Sensitivity to Measurement Duration:****Calibration Standards Required:****Property Measurement Comments:**

5%

60 min.

Uncertainty is improved by increasing measurement duration.

<10 Standards.

The measurement duration is highly dependent upon the measurement uncertainty requirements. Measurement times could be less if higher uncertainties are acceptable.

SNF-specific calibration standards are not required.

Limiting SNF Attribute # 1**Attribute Value:****Limiting Attribute Comment:**

No Limitation

No Limitation

SNF Property # 2

Performance Goal:

Meets Performance Goal:

Phenomena Measured:

Total Thermal Output for Disposable Canisters

No specific limit at this time.

Yes

For the Constant Temperature Servo-Control Method, the electrical current flowing into the Calorimeter is measured and the heat generated by the item being measured can be calculated directly.

Additional Information Required:

None

Measurement Uncertainty:

5%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

The measurement duration is highly dependent upon the measurement uncertainty requirements. Measurement times could be less if higher uncertainties are acceptable.

SNF-specific calibration standards are not required.

Limiting SNF Attribute # 1

No Limitation

Attribute Value:

No Limitation

Limiting Attribute Comment:

System Report

System Name:**Description:****Delayed Neutron NDA**

Uses neutron irradiation followed by measurement of delayed neutron emission. Irradiation using 14 MeV N. generator. Banks of 40 He-3 tubes for DN counting, 4 U-235 fission chambers for source monitoring. List mode data acquisition. Advanced data processing tools to determine fissionable isotopic content from aggregate DN signal.

The system can operate in a passive mode as well as looking for delayed neutrons.

SNF Experience:**Description of SNF Experience:****Non-SNF Experience:****Description of Non-SNF Experience:**

Field Deployed for Multiple SNF/Non-SNF.

Assays completed on cladding hulls and fast reactor blanket elements.

Field Deployed for Single SNF/Non-SNF.

Assays completed using non-irradiated materials. Passive measurements performed to determine alpha-n and SF neutron emissions.

Funded Development:**Operating Environment:****R and D Costs:****Procurement Costs:****In-Cell Space:****Out-Cell Space:****O and M Personnel:****R and D Schedule:****Deployment Schedule:****Measurable Configurations:****Additional Information:**

System deployed.

Dry Cell.

\$200K to \$1M

\$200K to \$1M

>100 sq. ft.

>100 sq. ft.

<1 FTE

1 to 2 yrs

<1 yr

Bare Fuel and Canisters

System deployed for 7" maximum height of sample. System modifications necessary to assay entire element.

SNF Property # 1**Performance Goal:****Meets Performance Goal:****Phenomena Measured:****Additional Information Required:**

Pu-239 content (weight % & g) (Post-Irradiation)

Key Property: +/- 70%

Yes

DN

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:**Measurement Duration:****Sensitivity to Measurement Duration:****Calibration Standards Required:****Property Measurement Comments:**

5%

100 min.

Uncertainty is improved by increasing measurement duration.

10 to 50 Standards.

System deployed for 7" maximum height of sample. System modifications necessary to assay entire element.

Requires knowledge of fuel geometry and material properties to calculate correction factors for self-absorption, etc.

Limiting SNF Attribute # 1**Attribute Value:****Limiting Attribute Comment:**

Gross neutron radiation (based on PWR assembly)

>1E+08 neutron/assy/sec

SNF Property # 2 Total Fissile Material in Disposable Canister
Performance Goal: Key Property: +/- 70%
Meets Performance Goal: Yes
Phenomena Measured: DN
Additional Information Required: None

Measurement Uncertainty: 5%
Measurement Duration: 60 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: System deployed for 7" maximum height of sample. System modifications necessary to assay entire element.
Uncertainty is improved by knowledge of fuel geometry and material properties to calculate correction factors for self-absorption, etc.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 3 U-233 content, (Post-irradiation) (weight % & g)
Performance Goal: Key Property: +/- 70%
Meets Performance Goal: Yes
Phenomena Measured: DN
Additional Information Required:

Other (Identified in Property Measurement Comments)

Measurement Uncertainty: 5%
Measurement Duration: 100 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: 10 to 50 Standards.
Property Measurement Comments: System deployed for 7" maximum height of sample. System modifications necessary to assay entire element.
Requires knowledge of fuel geometry and material properties to calculate correction factors for self-absorption, etc.

Limiting SNF Attribute # 1 Gross neutron radiation (based on PWR assembly)
Attribute Value: >1E+08 neutron/assy/sec
Limiting Attribute Comment:

SNF Property # 4	U-235 content, (Post-irradiation) (weight % & g)
Performance Goal:	Key Property: +/- 70%
Meets Performance Goal:	Yes
Phenomena Measured:	DN
Additional Information Required:	
	Other (Identified in Property Measurement Comments)
Measurement Uncertainty:	5%
Measurement Duration:	100 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	10 to 50 Standards.
Property Measurement Comments:	System deployed for 7" maximum height of sample. System modifications necessary to assay entire element. Requires knowledge of fuel geometry and material properties to calculate correction factors for self-absorption, etc.
Limiting SNF Attribute # 1	Gross neutron radiation (based on PWR assembly)
Attribute Value:	>1E+08 neutron/assy/sec
Limiting Attribute Comment:	
SNF Property # 5	U-238 content (Post-irradiation)
Performance Goal:	Key Property: No limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	DN
Additional Information Required:	
	Other (Identified in Property Measurement Comments)
Measurement Uncertainty:	5%
Measurement Duration:	100 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	10 to 50 Standards.
Property Measurement Comments:	System deployed for 7" maximum height of sample. System modifications necessary to assay entire element. Requires knowledge of fuel geometry and material properties to calculate correction factors for self-absorption, etc.
Limiting SNF Attribute # 1	Gross neutron radiation (based on PWR assembly)
Attribute Value:	>1E+08 neutron/assy/sec
Limiting Attribute Comment:	

SNF Property # 6 Enrichment (post-irradiation) (% U-235)
Performance Goal: Key Property: +/- 10%
Meets Performance Goal: Yes
Phenomena Measured: DN
Additional Information Required:

Other (Identified in Property Measurement Comments)

Measurement Uncertainty: 5%
Measurement Duration: 100 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: 10 to 50 Standards.
Property Measurement Comments: System deployed for 7" maximum height of sample. System modifications necessary to assay entire element.
Requires knowledge of fuel geometry and material properties to calculate correction factors for self-absorption, etc.

Limiting SNF Attribute # 1 Gross neutron radiation (based on PWR assembly)
Attribute Value: >1E+08 neutron/assy/sec
Limiting Attribute Comment:

SNF Property # 7 Total U content (post-irradiation) (g)
Performance Goal: +/- 70%
Meets Performance Goal: Yes
Phenomena Measured: DN, SF
Additional Information Required:

Other (Identified in Property Measurement Comments)

Measurement Uncertainty: 5%
Measurement Duration: 100 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: 10 to 50 Standards.
Property Measurement Comments: System deployed for 7" maximum height of sample. System modifications necessary to assay entire element.
Requires knowledge of fuel geometry and material properties to calculate correction factors for self-absorption, etc.

Limiting SNF Attribute # 1 Gross neutron radiation (based on PWR assembly)
Attribute Value: >1E+08 neutron/assy/sec
Limiting Attribute Comment:

SNF Property # 8 Total Pu content (post-irradiation) (g)
Performance Goal: +/- 70%
Meets Performance Goal: Yes
Phenomena Measured: DN, SF
Additional Information Required:

Other (Identified in Property Measurement Comments)

Measurement Uncertainty: 5%
Measurement Duration: 100 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: 10 to 50 Standards.
Property Measurement Comments: System deployed for 7" maximum height of sample. System modifications necessary to assay entire element.
Requires knowledge of fuel geometry and material properties to calculate correction factors for self-absorption, etc.

Limiting SNF Attribute # 1 Gross neutron radiation (based on PWR assembly)
Attribute Value: >1E+08 neutron/assy/sec
Limiting Attribute Comment:

SNF Property # 9 Burnup (MWD/MTHM)
Performance Goal: +/- Factor of 3 to 10
Meets Performance Goal: Yes
Phenomena Measured: DN, SF
Additional Information Required:

Other (Identified in Property Measurement Comments)

Measurement Uncertainty: 5%
Measurement Duration: 60 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: System deployed for 7" maximum height of sample. System modifications necessary to assay entire element.
Requires knowledge of fuel geometry and material properties to calculate correction factors for self-absorption, etc.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 10
Performance Goal: Gross neutron flux
 No specific limit at this time.
Meets Performance Goal: Yes
Phenomena Measured: Neutron
Additional Information Required: None

Measurement Uncertainty: 5%
Measurement Duration: 60 min.
Sensitivity to Measurement Duration: Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: System deployed for 7" maximum height of sample. System modifications necessary to assay entire element.
 No knowledge of fuel geometry and material properties is needed to determine the neutron flux leaving the waste package.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 11
Performance Goal: Pu-238 & Pu-240 content (weight %) (Post-Irradiation)
 No specific limit at this time.
Meets Performance Goal: Yes
Phenomena Measured: DN, SF
Additional Information Required:

Other (Identified in Property Measurement Comments)

Measurement Uncertainty: 5%
Measurement Duration: 100 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: 10 to 50 Standards.
Property Measurement Comments: System deployed for 7" maximum height of sample. System modifications necessary to assay entire element.
 Requires knowledge of fuel geometry and material properties to calculate correction factors for self-absorption, etc.

Limiting SNF Attribute # 1 Gross neutron radiation (based on PWR assembly)
Attribute Value: >1E+08 neutron/assy/sec
Limiting Attribute Comment:

SNF Property # 12 U-232 content (Post-irradiation) (ppm, if applicable)
Performance Goal: No specific limit at this time.
Meets Performance Goal: Yes
Phenomena Measured: SF
Additional Information Required:

Other (Identified in Property Measurement Comments)

Measurement Uncertainty: 5%
Measurement Duration: 100 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: Dependant on mix of isotopes in system.
System deployed for 7" maximum height of sample. System modifications necessary to assay entire element.
Requires knowledge of fuel geometry and material properties to calculate correction factors for self-absorption, etc.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 13 k-eff
Performance Goal: < 0.95 after bias/uncertainty
Meets Performance Goal: Yes
Phenomena Measured: DN, SF
Additional Information Required:

Other (Identified in Property Measurement Comments)

Measurement Uncertainty: 5%
Measurement Duration: 60 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: System deployed for 7" maximum height of sample. System modifications necessary to assay entire element.
Requires knowledge of fuel geometry and material properties to calculate correction factors for self-absorption, etc.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

System Report

System Name:**Description:****Directional Neutron Detector**

Measures gross, thermal neutrons from sources that also emit high gamma-ray flux. The detector contains multiple He-3 tubes that are unmoderated. Directionality is achieved by boron (B-10) coating on back and sides of detector package, plus B-10 on a front collimator. The directionality of the detector reduces the background counts. Operation with high-gamma-ray flux sources (1000 R/h) is possible by separating the detector from the source by distances of several meters. Neutron signal lost in separation distance is partially recovered by a graphite moderator/reflector placed behind and on the sides of the source. The moderator/reflector scatters neutrons and slows them down, increasing the thermal neutron flux in the direction of the detector.

SNF Experience:**Description of SNF Experience:****Non-SNF Experience:****Description of Non-SNF Experience:**

None.

Proof of Principle.

The directional neutron detector (without the moderator/reflector near the source) was originally developed to detect neutron sources, such as warheads containing plutonium, at a distance. The detector has been built and preliminary tests have been conducted. The concept of using a moderator/reflector near a neutron source is being evaluated for proof of principle in application to counting radioactive waste containers that emit high gamma-ray or beta flux and interfere with traditional neutron methods for measuring transuranic waste content.

Funded Development:**Operating Environment:****R and D Costs:****Procurement Costs:****In-Cell Space:****Out-Cell Space:****O and M Personnel:****R and D Schedule:****Deployment Schedule:****Measurable Configurations:****Additional Information:**

Not funded for SNF

Dry Cell.

\$200K to \$1M

<\$200K

10 to 50 sq. ft.

10 to 50 sq. ft.

<1 FTE

2 to 4 yrs

1 to 2 yrs

Bare Fuel and Canisters

SNF Property # 1**Performance Goal:****Meets Performance Goal:****Phenomena Measured:**

Pu-239 content (weight % & g) (Post-Irradiation)

Key Property: +/- 70%

Yes

Measures gross, thermal neutrons from sources that also emit high gamma-ray flux.

Additional Information Required:

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:**Measurement Duration:****Sensitivity to Measurement Duration:****Calibration Standards Required:****Property Measurement Comments:**

30%

15 min.

Uncertainty is improved by increasing measurement duration.

<10 Standards.

Information on geometry is required.

Limiting SNF Attribute # 1 Fuel unit poison material
Attribute Value: Boron
Attribute Value: Cadmium
Attribute Value: Erbium
Attribute Value: Gadolinium

Limiting Attribute Comment:

SNF Property # 2 Total Pu content (post-irradiation) (g)
Performance Goal: +/- 70%
Meets Performance Goal: Yes
Phenomena Measured: Measures gross, thermal neutrons from sources that also emit high gamma-ray flux.

Additional Information Required:

Other (Identified in Property Measurement Comments)

Measurement Uncertainty: 30%
Measurement Duration: 15 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments:

Limiting SNF Attribute # 1 Fuel unit poison material
Attribute Value: Boron
Attribute Value: Cadmium
Attribute Value: Erbium
Attribute Value: Gadolinium

Limiting Attribute Comment:

SNF Property # 3 Gross neutron flux
Performance Goal: No specific limit at this time.
Meets Performance Goal: Yes
Phenomena Measured: Measures gross, thermal neutrons from sources that also emit high gamma-ray flux.

Additional Information Required: None

Measurement Uncertainty: 30%
Measurement Duration: 15 min.
Sensitivity to Measurement Duration: Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments:

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation

Limiting Attribute Comment:

SNF Property # 4

Performance Goal:

Meets Performance Goal:

Phenomena Measured:

Pu-238 & Pu-240 content (weight %) (Post-Irradiation)

No specific limit at this time.

Yes

Measures gross, thermal neutrons from sources that also emit high gamma-ray flux.

Additional Information Required:

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:

30%

Measurement Duration:

15 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

System Report

System Name:**Description:****Dual-Slab Passive Neutron Counter**

This system detects neutron emission from Multi-Element Spent Fuel Storage Casks and compensates automatically for varying backgrounds. It is used to verify continuity of knowledge of spent fuel casks by periodic re-measurement and comparison to the initial verification measurement (continuity verification mode). It can also be used to verify the contents when no initial verification measurement has been made (continuity establishment mode). The limitation of the Dual-Slab detector is that it only measures Cm content; it does not measure the fissile content or the plutonium content directly. These data must be inferred using reactor burnup codes.

SNF Experience:**Description of SNF Experience:**

Field Deployed for Multiple SNF/Non-SNF.

This system has been field deployed by the IAEA for verification of LWR SNF in Multi-Element casks in the Gorleben storage facility in Germany.

Non-SNF Experience:**Description of Non-SNF Experience:**

None.

Funded Development:

This system is essentially developed. The only future development would be tailoring detectors and calibrating specific spent fuel configurations

Operating Environment:

Dry Cell.

R and D Costs:

<\$200K

Procurement Costs:

<\$200K

In-Cell Space:

<10 sq. ft.

Out-Cell Space:

<10 sq. ft.

O and M Personnel:

<1 FTE

R and D Schedule:

<1 yr

Deployment Schedule:

<1 yr

Measurable Configurations:

Canister

Additional Information:

The system measures shielded storage casks.

SNF Property # 1**Performance Goal:****Meets Performance Goal:****Phenomena Measured:****Additional Information Required:**

Pu-239 content (weight % & g) (Post-Irradiation)

Key Property: +/- 70%

Yes

Neutron flux from Cm-244. Pu is inferred by association.

BOL Enrichment

Burnup Other (Identified in Property Measurement Comments)
Reactor Design and Neutronics**Measurement Uncertainty:**

1%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

Irradiation history information is also required.

In the continuity verification mode, an initial measurement is made on the cask at a point in time when the contents of the cask are known and assured by surveillance. Subsequent measurements are then performed at later times to re-verify the contents of the cask. The source of the neutron emission (Cm-244) is verified by observation of the half-life.

In the continuity establishment mode, a family of similar casks are measured for calibration with source term strength corrections from initial FORK measurement data (or ORIGEN2 calculations). The "unknown" cask neutron flux is measured and compared against its predicted flux using declared values for the contents (initial mass, fuel enrichment, burnup, irradiation history, age).

Limiting SNF Attribute # 1

Container wet/dry

Attribute Value: Contents partially or fully flooded**Limiting Attribute Comment:****Limiting SNF Attribute # 2**

Fuel unit poison material

Attribute Value: Boron**Attribute Value:** Cadmium**Attribute Value:** Erbium**Attribute Value:** Gadolinium**Limiting Attribute Comment:****Limiting SNF Attribute # 3**

Gross neutron radiation (based on PWR assembly)

Attribute Value: 1E+06 to 1E+08 neutron/assy/sec**Attribute Value:** >1E+08 neutron/assy/sec**Limiting Attribute Comment:**

SNF Property # 2**Performance Goal:****Meets Performance Goal:****Phenomena Measured:****Additional Information Required:**

Total Pu content (post-irradiation) (g)

+/- 70%

Yes

Neutron flux from Cm-244. Pu is inferred by association.

BOL Enrichment

Burnup

Other (Identified in Property Measurement Comments)
Reactor Design and Neutronics**Measurement Uncertainty:**

1%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

10 to 50 Standards.

Property Measurement Comments:

Irradiation history information is also required.

In the continuity verification mode, an initial measurement is made on the cask at a point in time when the contents of the cask are known and assured by surveillance. Subsequent measurements are then performed at later times to re-verify the contents of the cask. The source of the neutron emission (Cm-244) is verified by observation of the half-life.

In the continuity establishment mode, a family of similar casks are measured for calibration with source term strength corrections from initial FORK measurement data (or ORIGEN2 calculations). The "unknown" cask neutron flux is measured and compared against its predicted flux using declared values for the contents (initial mass, fuel enrichment, burnup, irradiation history, age).

Limiting SNF Attribute # 1

Container wet/dry

Attribute Value: Contents partially or fully flooded**Limiting Attribute Comment:**

The fuel age is also a limitation. Fuel cannot have been removed from the reactor for more than 10 years.

Limiting SNF Attribute # 2

Fuel unit poison material

Attribute Value: Boron**Attribute Value:** Cadmium**Attribute Value:** Erbium**Attribute Value:** Gadolinium**Limiting Attribute Comment:****Limiting SNF Attribute # 3**

Gross neutron radiation (based on PWR assembly)

Attribute Value: 1E+06 to 1E+08 neutron/assy/sec**Attribute Value:** >1E+08 neutron/assy/sec**Limiting Attribute Comment:**

SNF Property # 3**Performance Goal:****Meets Performance Goal:****Phenomena Measured:****Additional Information Required:**

Gross neutron flux

No specific limit at this time.

Yes

Neutron flux from Cm-244. Pu is inferred by association.

None

Measurement Uncertainty:

1%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is not improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

Irradiation history information is also required.

In the continuity verification mode, an initial measurement is made on the cask at a point in time when the contents of the cask are known and assured by surveillance. Subsequent measurements are then performed at later times to re-verify the contents of the cask. The source of the neutron emission (Cm-244) is verified by observation of the half-life.

In the continuity establishment mode, a family of similar casks are measured for calibration with source term strength corrections from initial FORK measurement data (or ORIGEN2 calculations). The "unknown" cask neutron flux is measured and compared against its predicted flux using declared values for the contents (initial mass, fuel enrichment, burnup, irradiation history, age).

Limiting SNF Attribute # 1

No Limitation

Attribute Value:

No Limitation

Limiting Attribute Comment:

SNF Property # 4**Performance Goal:****Meets Performance Goal:****Phenomena Measured:****Additional Information Required:**

Pu-238 & Pu-240 content (weight %) (Post-Irradiation)

No specific limit at this time.

Yes

Neutron flux from Cm-244. Pu is inferred by association.

BOL Enrichment

Burnup Other (Identified in Property Measurement Comments)
Reactor Design and Neutronics**Measurement Uncertainty:**

1%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

Irradiation history information is also required.

In the continuity verification mode, an initial measurement is made on the cask at a point in time when the contents of the cask are known and assured by surveillance. Subsequent measurements are then performed at later times to re-verify the contents of the cask. The source of the neutron emission (Cm-244) is verified by observation of the half-life.

In the continuity establishment mode, a family of similar casks are measured for calibration with source term strength corrections from initial FORK measurement data (or ORIGEN2 calculations). The "unknown" cask neutron flux is measured and compared against its predicted flux using declared values for the contents (initial mass, fuel enrichment, burnup, irradiation history, age).

Limiting SNF Attribute # 1

Container wet/dry

Attribute Value:*Contents partially or fully flooded***Limiting Attribute Comment:****Limiting SNF Attribute # 2**

Fuel unit poison material

Attribute Value:*Boron***Attribute Value:***Cadmium***Attribute Value:***Erbium***Attribute Value:***Gadolinium***Limiting Attribute Comment:****Limiting SNF Attribute # 3**

Gross neutron radiation (based on PWR assembly)

Attribute Value:*1E+06 to 1E+08 neutron/assy/sec***Attribute Value:***>1E+08 neutron/assy/sec***Limiting Attribute Comment:**

System Report

System Name:	Fast Neutron Radiography
Description:	14 MeV neutrons from a neutron generator are transmitted through a sample and produce a 2-D radiograph of the sample.
SNF Experience:	Laboratory Development.
Description of SNF Experience:	Field Deployed for Single SNF/Non-SNF.
Non-SNF Experience:	
Description of Non-SNF Experience:	Funding is pending from outside sources (mainly military applications) to perform fast neutron radiography
Funded Development:	
Operating Environment:	Dry Cell.
R and D Costs:	\$200K to \$1M
Procurement Costs:	\$200K to \$1M
In-Cell Space:	10 to 50 sq. ft.
Out-Cell Space:	10 to 50 sq. ft.
O and M Personnel:	1 to 2 FTEs
R and D Schedule:	1 to 2 yrs
Deployment Schedule:	1 to 2 yrs
Measurable Configurations:	Bare Fuel and Canisters
Additional Information:	This is an examination technique that complements x-rays and thermal neutron radiography. It offers several advantages over these techniques in being able to examine thicker samples and penetrate thermal neutron absorbers
SNF Property # 1	Condition of fuel (intact, failed clad, degraded, etc.) (Text)
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	
Additional Information Required:	None
Measurement Uncertainty:	N.A. %
Measurement Duration:	15 min.
Sensitivity to Measurement Duration:	Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	
Limiting SNF Attribute # 1	Gross gamma radiation (based on PWR assembly)
Attribute Value:	<1E+09 photons/assy/sec
Limiting Attribute Comment:	Unsure of extent that gamma field will affect measurement.

SNF Property # 2 Fuel dimensions (pellet diameter, clad ID & OD, plate thickness, etc.) (cm)
Performance Goal: +/- 0.254 cm w; +/- 2.54 cm l
Meets Performance Goal: Yes
Phenomena Measured:
Additional Information Required: None

Measurement Uncertainty: 5%
Measurement Duration: 15 min.
Sensitivity to Measurement Duration: Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments:

Limiting SNF Attribute # 1 Gross gamma radiation (based on PWR assembly)
Attribute Value: <1E+09 photons/assy/sec
Limiting Attribute Comment: Unsure of extent that gamma field will affect measurement.

SNF Property # 3 Fuel rod pitch or plate spacing (cm)
Performance Goal: No specific limit at this time.
Meets Performance Goal: Yes
Phenomena Measured:
Additional Information Required: None

Measurement Uncertainty: 5%
Measurement Duration: 15 min.
Sensitivity to Measurement Duration: Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments:

Limiting SNF Attribute # 1 Gross gamma radiation (based on PWR assembly)
Attribute Value: <1E+09 photons/assy/sec
Limiting Attribute Comment:

System Report

System Name:**Description:****Fast Neutron Transmission Spectroscopy**

Fast neutron transmission through items is used to determine the light element (H, C, O, N) contents. Transmission is measured as a function of energy using time of flight by a series of collimated neutron detectors.

SNF Experience:**Description of SNF Experience:****Non-SNF Experience:****Description of Non-SNF Experience:****Funded Development:****Operating Environment:****R and D Costs:****Procurement Costs:****In-Cell Space:****Out-Cell Space:****O and M Personnel:****R and D Schedule:****Deployment Schedule:****Measurable Configurations:****Additional Information:**

None.

Proof of Principle.

Detection of explosives and drugs in suitcases has been demonstrated.

Dry Cell.

\$200K to \$1M

\$1M to \$5M

10 to 50 sq. ft.

10 to 50 sq. ft.

1 to 2 FTEs

1 to 2 yrs

1 to 2 yrs

Bare Fuel and Canisters

SNF Property # 1**Performance Goal:****Meets Performance Goal:****Phenomena Measured:**

Free Liquids in Canistered SNF

0.2 kg to 1.3 kg total water

Yes

Fast neutron transmission through items is used to determine the light elements.

Additional Information Required:

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:**Measurement Duration:****Sensitivity to Measurement Duration:****Calibration Standards Required:****Property Measurement Comments:**

20%

120 min.

Uncertainty is improved by increasing measurement duration.

<10 Standards.

Need to know rough geometry of fuel and estimate or measurement of gamma field.

Limiting SNF Attribute # 1**Attribute Value:****Limiting Attribute Comment:**

No Limitation

No Limitation

SNF Property # 2**Performance Goal:****Meets Performance Goal:****Phenomena Measured:**

Moisture content of fuel item (g)

No specific limit at this time.

Yes

Fast neutron transmission through items is used to determine the light elements.

Additional Information Required:

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:

20%

Measurement Duration:

120 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

Need to know rough geometry of fuel and estimate or measurement of gamma field.

Limiting SNF Attribute # 1

No Limitation

Attribute Value:

No Limitation

Limiting Attribute Comment:**SNF Property # 3****Performance Goal:****Meets Performance Goal:****Phenomena Measured:**

Moisture content of loaded canister (g)

0.2 kg to 1.3 kg total water

Yes

Fast neutron transmission through items is used to determine the light elements.

Additional Information Required:

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:

20%

Measurement Duration:

120 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

Need to know rough geometry of fuel and estimate or measurement of gamma field.

Limiting SNF Attribute # 1

No Limitation

Attribute Value:

No Limitation

Limiting Attribute Comment:

SNF Property # 4

Performance Goal:

Meets Performance Goal:

Phenomena Measured:

Organics

< 17 g to < 900 g per canister

Yes

Fast neutron transmission through items is used to determine the light elements.

Additional Information Required:

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:

20%

Measurement Duration:

120 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

Need to know rough geometry of fuel and estimate or measurement of gamma field.

Limiting SNF Attribute # 1

No Limitation

Attribute Value:

No Limitation

Limiting Attribute Comment:

System Report

System Name:**Description:****FORK**

The FORK detector measures the intensity of the neutrons and gamma rays produced in SNF. The neutron count rate is used to determine burnup, while the gamma-ray count rate is combined with the deduced burnup to determine the cooling time. It is important to know the initial enrichment from records because the neutron count rate is greatly affected by it. A code such as CINDER, ORIGEN2, or ORIGEN-ARP can be used to make an adjustment for the initial enrichment to the neutron count rate so that only one calibration curve is used and it is good for all initial enrichments and operating histories. The cooling time need not be known in advance. However, if the initial enrichment, initial loading, irradiation history, and the cooling off period are all known, then the data from this measurement can be used to infer the total plutonium content, the total reactivity (fissile material content), and the radionuclide inventory, as well. These are also determined using reactor burnup codes, such as CINDER. The burnup codes require the initial fuel enrichment and composition and the total burnup, which is measured by the FORK detector. The FORK detector is easily the most widely deployed spent fuel measurement technology and has been deployed in dozens of instances.

The FORK detector works on essentially all spent fuel types; however, the error increases with the level of enrichment. The limitation of the FORK detector is that it only measures burnup; it does not measure the fissile content or the plutonium content directly. These data must be inferred using reactor burnup codes.

SNF Experience:**Description of SNF Experience:****Non-SNF Experience:****Description of Non-SNF Experience:****Funded Development:****Operating Environment:****R and D Costs:****Procurement Costs:****In-Cell Space:****Out-Cell Space:****O and M Personnel:****R and D Schedule:****Deployment Schedule:****Measurable Configurations:****Additional Information:**

Field Deployed for Multiple SNF/Non-SNF.

The fork is probably the most field-tested and proven SNF system.

None.

Already developed.

Underwater and Dry Cell.

<\$200K

<\$200K

<10 sq. ft.

<10 sq. ft.

<1 FTE

None

<1 yr

Bare Fuel

There is no R&D cost.

SNF Property # 1**Performance Goal:****Meets Performance Goal:****Phenomena Measured:****Additional Information Required:**

Pu-239 content (weight % & g) (Post-Irradiation)

Key Property: +/- 70%

Yes

Gross Gamma and Gross neutron flux.

BOL Enrichment

Other (Identified in Property Measurement Comments)
Reactor Design and Neutronics**Measurement Uncertainty:**

10%

Measurement Duration:

5 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

10 to 50 Standards.

Property Measurement Comments:

Additional information is also required on irradiation profile (not entire irradiation history), initial loading, and fuel geometry.

SNF Property # 2**Performance Goal:****Meets Performance Goal:****Phenomena Measured:****Additional Information Required:**

Total Pu content (post-irradiation) (g)

+/- 70%

Yes

Gross Gamma and Gross neutron flux.

BOL Enrichment

Other (Identified in Property Measurement Comments)
Reactor Design and Neutronics**Measurement Uncertainty:**

10%

Measurement Duration:

5 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

10 to 50 Standards.

Property Measurement Comments:

Additional information is also required on irradiation profile (not entire irradiation history), initial loading, and fuel geometry.

SNF Property # 3**Performance Goal:****Meets Performance Goal:****Phenomena Measured:****Additional Information Required:**

Burnup (MWD/MTHM)

+/- Factor of 3 to 10

Yes

Gross Gamma and Gross neutron flux.

BOL Enrichment

Other (Identified in Property Measurement Comments)
Reactor Design and Neutronics**Measurement Uncertainty:**

10%

Measurement Duration:

5 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

10 to 50 Standards.

Property Measurement Comments:

Additional information is also required on irradiation profile (not entire irradiation history), initial loading, and fuel geometry.

Limiting SNF Attribute # 1 No Limitation**Attribute Value:** No Limitation**Limiting Attribute Comment:**

SNF Property # 4	Gross gamma flux
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	Gross gamma flux.
Additional Information Required:	None
Measurement Uncertainty:	5%
Measurement Duration:	5 min.
Sensitivity to Measurement Duration:	Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	
Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	
SNF Property # 5	Gross neutron flux
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	Gross neutron flux.
Additional Information Required:	None
Measurement Uncertainty:	5%
Measurement Duration:	5 min.
Sensitivity to Measurement Duration:	Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	
Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	
SNF Property # 6	Pu-238 & Pu-240 content (weight %) (Post-Irradiation)
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	Gross Gamma and Gross neutron flux.
Additional Information Required:	BOL Enrichment
	Other (Identified in Property Measurement Comments)
	Reactor Design and Neutronics
Measurement Uncertainty:	10%
Measurement Duration:	5 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	10 to 50 Standards.
Property Measurement Comments:	Additional information is also required on irradiation profile (not entire irradiation history), initial loading, and fuel geometry.

System Report

System Name:**Description:****Fork Plus (Advanced Fork Detector)**

A spent fuel assay system that cradles fuel assembly using 1) CdZnTe detector (thermionically-cooled) for gamma-ray spectroscopy, 2) ion chamber chamber for gross gamma-ray measurements, and 3) fission chamber for gross neutron measurements. System is operated underwater in spent fuel pool.

SNF Experience:**Description of SNF Experience:**

Field Deployed for Single SNF/Non-SNF.

Detection system has been used for prototype measurement campaign at Maine Yankee.

Non-SNF Experience:**Description of Non-SNF Experience:**

Laboratory Development.

Calibration at laboratory using Cs-137.

Funded Development:

System developed and demonstrated for burnup of PWR fuels.

Operating Environment:

Underwater.

R and D Costs:

\$200K to \$1M

Procurement Costs:

<\$200K

In-Cell Space:

<10 sq. ft.

Out-Cell Space:

<10 sq. ft.

O and M Personnel:

1 to 2 FTEs

R and D Schedule:

<1 yr

Deployment Schedule:

<1 yr

Measurable Configurations:

Bare Fuel

Additional Information:

Canisters and barrels possible

SNF Property # 1**Performance Goal:**

Pu-239 content (weight % & g) (Post-Irradiation)

Meets Performance Goal:

Key Property: +/- 70%

Phenomena Measured:

Yes

Additional Information Required:

BOL Enrichment

Last Date of Irradiation

Reactor Design and Neutronics

Measurement Uncertainty:

10%

Measurement Duration:

30 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

SNF Property # 2	Total Pu content (post-irradiation) (g)
Performance Goal:	+/- 70%
Meets Performance Goal:	Yes
Phenomena Measured:	
Additional Information Required:	BOL Enrichment
	Last Date of Irradiation
	Reactor Design and Neutronics
Measurement Uncertainty:	10%
Measurement Duration:	30 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	
SNF Property # 3	Activation products (Ci)
Performance Goal:	+/- Factor of 3 to 10
Meets Performance Goal:	Yes
Phenomena Measured:	Gammas from activation products.
Additional Information Required:	None
Measurement Uncertainty:	10%
Measurement Duration:	30 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	
Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	
SNF Property # 4	Burnup (MWD/MTHM)
Performance Goal:	+/- Factor of 3 to 10
Meets Performance Goal:	Yes
Phenomena Measured:	Determine spent fuel burn up from measured Cs-137 gamma-ray energies and emission rates. (Goal of +/- 25%.)
Additional Information Required:	BOL Enrichment
	Last Date of Irradiation
	Reactor Design and Neutronics
Measurement Uncertainty:	10%
Measurement Duration:	30 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 5 Gross gamma flux
Performance Goal: No specific limit at this time.
Meets Performance Goal: Yes
Phenomena Measured: Measured ion chamber current proportional to total gamma flux. (Asymmetry of irradiation of fuel assembly can also be determined.)
Additional Information Required: None

Measurement Uncertainty: 20%
Measurement Duration: 1 min.
Sensitivity to Measurement Duration: Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: Only one calibration standard (Cs-137) needed.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 6 Gross neutron flux
Performance Goal: No specific limit at this time.
Meets Performance Goal: Yes
Phenomena Measured: Measure gross neutron flux with fission chamber.
Additional Information Required: None

Measurement Uncertainty: 10%
Measurement Duration: 17 min.
Sensitivity to Measurement Duration: Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: Relative measurement of burn up determined. (No calibration standards needed.) (Uncertainty inversely proportional to square root of measured duration.)

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 7**Performance Goal:****Meets Performance Goal:****Phenomena Measured:****Additional Information Required:**

Pu-238 & Pu-240 content (weight %) (Post-Irradiation)

No specific limit at this time.

Yes

BOL Enrichment

Last Date of Irradiation

Reactor Design and Neutronics

Measurement Uncertainty:

10%

Measurement Duration:

30 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:**SNF Property # 8**

Ac227;Am241/2m/3;C14;Cl36;Cm244/5/6;Cs135;Nb93m/94;Ni59/63;Pa231;Pb210;Pd107;Pu242;Ra226/8;Se79;Sm151;Sn126;Th-229/230;Zr93 (Ci/package)

Performance Goal:

No specific limit at this time.

Meets Performance Goal:

Yes

Phenomena Measured:**Additional Information Required:**

None

Measurement Uncertainty:

10%

Measurement Duration:

30 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

Only some of the radionuclides can be measured. The other radionuclides can be inferred from depletion code calculations.

Limiting SNF Attribute # 1 No Limitation**Attribute Value:** No Limitation**Limiting Attribute Comment:**

System Report

System Name:**Description:****Gamma Spectroscopy**

The virtues and attributes of high resolution gamma-ray spectroscopy are commonly understood and appreciated by all who work in the field. The PNNL has a few unique capabilities for handling spectral data from germanium detectors which can expand application of gamma-ray spectroscopy in some circumstances. Specifically, PNNL has software to automatically energy align and combine spectra from multiple detectors, software to analyze statistically noisy spectra, software for automatic internal energy calibration, and software to provide time-stamp list mode data for building separate spectra from moving sources or building coincidence spectra from multiple detectors.

SNF Experience:**Description of SNF Experience:****Non-SNF Experience:****Description of Non-SNF Experience:****Funded Development:****Operating Environment:****R and D Costs:****Procurement Costs:****In-Cell Space:****Out-Cell Space:****O and M Personnel:****R and D Schedule:****Deployment Schedule:****Measurable Configurations:****Additional Information:**

Laboratory Development.

Field Deployed for Multiple SNF/Non-SNF.

Underwater and Dry Cell.

\$200K to \$1M

\$200K to \$1M

<10 sq. ft.

<10 sq. ft.

<1 FTE

1 to 2 yrs

1 to 2 yrs

Bare Fuel and Canisters

SNF Property # 1**Performance Goal:****Meets Performance Goal:****Phenomena Measured:****Additional Information Required:**

Activation products (Ci)

+/- Factor of 3 to 10

Yes

None

Measurement Uncertainty:**Measurement Duration:****Sensitivity to Measurement Duration:****Calibration Standards Required:****Property Measurement Comments:****Limiting SNF Attribute # 1****Attribute Value:****Limiting Attribute Comment:**

10%

5 min.

Uncertainty is improved by increasing measurement duration.

<10 Standards.

Not all activation products can necessarily be measured.

No Limitation

No Limitation

SNF Property # 2	Burnup (MWD/MTHM)
Performance Goal:	+/- Factor of 3 to 10
Meets Performance Goal:	Yes
Phenomena Measured:	
Additional Information Required:	BOL Enrichment
	Last Date of Irradiation
	Reactor Design and Neutronics
Measurement Uncertainty:	10%
Measurement Duration:	5 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	
Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	
SNF Property # 3	Gross gamma flux
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	
Additional Information Required:	None
Measurement Uncertainty:	10%
Measurement Duration:	5 min.
Sensitivity to Measurement Duration:	Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Need to know the bulk dimensions and distances.
Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	
SNF Property # 4	Ac227;Am241/2m/3;C14;Cl36;Cm244/5/6;Cs135;Nb93m/94;Ni59/63;Pa231;Pb210;Pd107;Pu242;Ra226/8;Se79;Sm151;Sn126;Th-229/230;Zr93 (Ci/package)
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	
Additional Information Required:	None
Measurement Uncertainty:	10%
Measurement Duration:	5 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Calibration standards required for each type of fuel.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

System Report

System Name:**Description:****Gamma-ray Spectroscopy CdZnTe or HPGe**

CdZnTe detectors are compact medium resolution, uncooled gamma-ray spectrometric detectors. A spent fuel assay system using these devices requires less shielding than HPGe, do not require LN2 cooling, and provide more detailed spectra than NaI detectors. System could be operated with either HPGe or CdZnTe detectors.

SNF Experience:**Description of SNF Experience:**

Laboratory Development.

CdZnTe detector technology is rapidly improving. Some demonstration projects have demonstrated SNF measurements and may be very close to field deployment.

Non-SNF Experience:**Description of Non-SNF Experience:**

Field Deployed for Multiple SNF/Non-SNF.

Detectors have found use in a number of non-SNF applications such as medical imaging and space exploration.

Funded Development:**Operating Environment:****R and D Costs:****Procurement Costs:****In-Cell Space:****Out-Cell Space:****O and M Personnel:****R and D Schedule:****Deployment Schedule:****Measurable Configurations:****Additional Information:**

System is under development for Burn up confirmation on FRR fuels

Dry Cell.

<\$200K

<\$200K

<10 sq. ft.

<10 sq. ft.

<1 FTE

<1 yr

<1 yr

Bare Fuel and Canisters

SNF Property # 1**Performance Goal:****Meets Performance Goal:****Phenomena Measured:**

Activation products (Ci)

+/- Factor of 3 to 10

Yes

ONLY gamma-ray emitting activation products are directly measured. Non gamma-emitting nuclides would be calculated.

Additional Information Required:

None

Measurement Uncertainty:**Measurement Duration:****Sensitivity to Measurement Duration:****Calibration Standards Required:****Property Measurement Comments:**

50%

60 min.

Uncertainty is improved by increasing measurement duration.

<10 Standards.

Quantitative uncertainty primarily dependant on fuel detector geometry.

Limiting SNF Attribute # 1

No Limitation

Attribute Value:

No Limitation

Limiting Attribute Comment:

SNF Property # 2	Burnup (MWD/MTHM)
Performance Goal:	+/- Factor of 3 to 10
Meets Performance Goal:	Yes
Phenomena Measured:	Determine fission product isotopic ratios from gamma-ray energies and emission rates
Additional Information Required:	BOL Enrichment Last Date of Irradiation Reactor Design and Neutronics
Measurement Uncertainty:	30%
Measurement Duration:	60 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Can determine both Burn Up and Last date of irradiation if sufficient fission product ratios can be quantified.
Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	
SNF Property # 3	Gross gamma flux
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	Integrate gamma rays detected in given counting period.
Additional Information Required:	None
Measurement Uncertainty:	20%
Measurement Duration:	10 min.
Sensitivity to Measurement Duration:	Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Use of geometry, bulk dimensions, and distances may be used to reduce the uncertainty.
Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	

SNF Property # 4

Ac227;Am241/2m/3;C14;Cl36;Cm244/5/6;Cs135;Nb93m/94;Ni59/63;Pa231;Pb210;Pd107;Pu242;Ra226/8;Se79;Sm151;Sn126;Th-229/230;Zr93 (Ci/package)

Performance Goal:

No specific limit at this time.

Meets Performance Goal:

Yes

Phenomena Measured:

Determine fission product isotopic ratios from gamma-ray energies and emission rates

Additional Information Required:

None

Measurement Uncertainty:

30%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

Can determine both Burn Up and Last date of irradiation if sufficient fission product ratios can be quantified.

Limiting SNF Attribute # 1

No Limitation

Attribute Value:

No Limitation

Limiting Attribute Comment:

System Report

System Name:	Low-level 90Sr Detector for Aqueous Samples
Description:	This inexpensive system can measure, in-situ, extremely low levels of Sr-90 (90Y) in water samples down to drinking water limits to monitor for cracks in underwater fuel rods.
SNF Experience:	None.
Description of SNF Experience:	
Non-SNF Experience:	Laboratory Development.
Description of Non-SNF Experience:	We've built a system for measuring near drinking water limits for environmental applications
Funded Development:	DOE EM --- PNNL internal Laboratory Directed Research and Development
Operating Environment:	Underwater.
R and D Costs:	\$200K to \$1M
Procurement Costs:	<\$200K
In-Cell Space:	<10 sq. ft.
Out-Cell Space:	<10 sq. ft.
O and M Personnel:	<1 FTE
R and D Schedule:	1 to 2 yrs
Deployment Schedule:	<1 yr
Measurable Configurations:	Canister
Additional Information:	Very small, inexpensive - less than 10K per copy.
SNF Property # 1	Disposable Canister Leak Rates
Performance Goal:	1x10 ⁻⁷ std cc/sec
Meets Performance Goal:	Yes
Phenomena Measured:	
Additional Information Required:	None
Measurement Uncertainty:	10%
Measurement Duration:	10 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Measurement can be affected by high flux - though the effect size is unknown.
Limiting SNF Attribute # 1	Gross gamma radiation (based on PWR assembly)
Attribute Value:	1E+09 to 1E+11 photons/assy/sec
Attribute Value:	1E+11 to 1E+13 photons/assy/sec
Attribute Value:	1E+13 to 1E+15 photons/assy/sec
Attribute Value:	>1E+15 photons/assy/sec
Limiting Attribute Comment:	Unknown effect of high gamma flux

SNF Property # 2**Performance Goal:****Meets Performance Goal:****Phenomena Measured:****Additional Information Required:**

Requirements that canisters be sealed

No specific limit at this time.

Yes

None

Measurement Uncertainty:**Measurement Duration:****Sensitivity to Measurement Duration:****Calibration Standards Required:****Property Measurement Comments:**

N.A.%

10 min.

Uncertainty is improved by increasing measurement duration.

<10 Standards.

Measurement can be affected by high flux - though the effect size is unknown.

Limiting SNF Attribute # 1**Attribute Value:****Attribute Value:****Attribute Value:****Attribute Value:****Limiting Attribute Comment:**

Gross gamma radiation (based on PWR assembly)

1E+09 to 1E+11 photons/assy/sec

1E+11 to 1E+13 photons/assy/sec

1E+13 to 1E+15 photons/assy/sec

>1E+15 photons/assy/sec

System Report

System Name:**Description:****Multi-Detector Analysis System**

The MDAS system is a coincident radiation based detection system. It uses both gamma ray and neutron detectors. The systems detects fast neutrons (greater than 40 Kev) and high energy gamma rays (greater than 1 Mev).

The MDAS system is currently under development and intended for use for the analysis of spent nuclear fuel. FATS determines total fissile quantity in fissile equivalents (e.g., uranium or plutonium) and GNAT determines isotopics with the ratios of fissile isotopes measured. Typically, fissile content of SNF with low enrichment and high burnup is difficult to measure due to the high curium content, which swamps the detectors. FATS and GNAT use a Short Die-Away Time Neutron Detector, which is not subject to this interference since it has a nanosecond window.

SNF Experience:**Description of SNF Experience:**

Laboratory Development.

Used on ARMF fuel in a test environment. Current experiments being conducted using spent EBR-II fuel.

Non-SNF Experience:**Description of Non-SNF Experience:**

Field Deployed for Single SNF/Non-SNF.

Used in START-II treaty verification. Plans are to test on TRU-waste this year. Currently funded by SNF programs, RH-TRU, and Advanced Mixed Waste programs for system development.

Funded Development:**Operating Environment:**

Dry Cell.

R and D Costs:

\$5M to \$10M

Procurement Costs:

\$5M to \$10M

In-Cell Space:

<10 sq. ft.

Out-Cell Space:

>100 sq. ft.

O and M Personnel:

<1 FTE

R and D Schedule:

2 to 4 yrs

Deployment Schedule:

2 to 4 yrs

Measurable Configurations:

Bare Fuel and Canisters

Additional Information:

The system can be deployed in, but does not require a hot cell use. The system is planned to be used a self-shielded system.

SNF Property # 1**Performance Goal:**

Pu-239 content (weight % & g) (Post-Irradiation)

Meets Performance Goal:

Key Property: +/- 70%

Phenomena Measured:

Yes

Additional Information Required:

Prompt fission products. Coincident gamma rays.

None

Measurement Uncertainty:

20%

Measurement Duration:

20 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

Duration is based on an 1E11 per second neutron source. No additional calibrations required for individual measurements. System is not geometry dependent.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 2 Pu-241 content (weight % & g) (Post-Irradiation)
Performance Goal: Key Property: +/- 70%
Meets Performance Goal: Yes
Phenomena Measured: Prompt fission products. Coincident gamma rays.
Additional Information Required: None

Measurement Uncertainty: 20%
Measurement Duration: 20 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: Duration is based on an 1E11 per second neutron source. No additional calibrations required for individual measurements. System is not geometry dependent.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 3 Radionuclide Content: Np-237
Performance Goal: Key Property: +/- Factor of 3 to 10
Meets Performance Goal: Yes
Phenomena Measured: Prompt fission products. Coincident gamma rays.
Additional Information Required: None

Measurement Uncertainty: 30%
Measurement Duration: 20 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: Duration is based on an 1E11 per second neutron source. No additional calibrations required for individual measurements. System is not geometry dependent.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 4	Total Fissile Material in Disposable Canister
Performance Goal:	Key Property: +/- 70%
Meets Performance Goal:	Yes
Phenomena Measured:	Prompt fission products. Coincident gamma rays.
Additional Information Required:	None

Measurement Uncertainty:	50%
Measurement Duration:	20 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Duration is based on an 1E11 per second neutron source. No additional calibrations required for individual measurements. System is not geometry dependent.

Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	

SNF Property # 5	U-233 content, (Post-irradiation) (weight % & g)
Performance Goal:	Key Property: +/- 70%
Meets Performance Goal:	Yes
Phenomena Measured:	Prompt fission products. Coincident gamma rays.
Additional Information Required:	None

Measurement Uncertainty:	20%
Measurement Duration:	20 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Duration is based on an 1E11 per second neutron source. No additional calibrations required for individual measurements. System is not geometry dependent.

Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	

SNF Property # 6 U-235 content, (Post-irradiation) (weight % & g)
Performance Goal: Key Property: +/- 70%
Meets Performance Goal: Yes
Phenomena Measured: Prompt fission products. Coincident gamma rays.
Additional Information Required: None

Measurement Uncertainty: 20%
Measurement Duration: 20 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: Duration is based on an 1E11 per second neutron source. No additional calibrations required for individual measurements. System is not geometry dependent.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 7 U-238 content (Post-irradiation)
Performance Goal: Key Property: No limit at this time.
Meets Performance Goal: Yes
Phenomena Measured: Prompt fission products. Coincident gamma rays.
Additional Information Required: None

Measurement Uncertainty: 20%
Measurement Duration: 20 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: Duration is based on an 1E11 per second neutron source. No additional calibrations required for individual measurements. System is not geometry dependent.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 8	Enrichment (post-irradiation) (% U-235)
Performance Goal:	Key Property: +/- 10%
Meets Performance Goal:	Yes
Phenomena Measured:	Prompt fission products. Coincident gamma rays.
Additional Information Required:	None

Measurement Uncertainty:	15%
Measurement Duration:	20 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Duration is based on an 1E11 per second neutron source. No additional calibrations required for individual measurements. System is not geometry dependent.

Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	

SNF Property # 9	Total U content (post-irradiation) (g)
Performance Goal:	+/- 70%
Meets Performance Goal:	Yes
Phenomena Measured:	Prompt fission products. Coincident gamma rays.
Additional Information Required:	None

Measurement Uncertainty:	20%
Measurement Duration:	20 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Duration is based on an 1E11 per second neutron source. No additional calibrations required for individual measurements. System is not geometry dependent.

Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	

SNF Property # 10 Total Pu content (post-irradiation) (g)
Performance Goal: +/- 70%
Meets Performance Goal: Yes
Phenomena Measured: Prompt fission products. Coincident gamma rays.
Additional Information Required: None

Measurement Uncertainty: 20%
Measurement Duration: 20 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: Duration is based on an 1E11 per second neutron source. No additional calibrations required for individual measurements. System is not geometry dependent.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 11 Activation products (Ci)
Performance Goal: +/- Factor of 3 to 10
Meets Performance Goal: Yes
Phenomena Measured: Prompt fission products. Coincident gamma rays.
Additional Information Required: None

Measurement Uncertainty: 30%
Measurement Duration: 20 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: Duration is based on an 1E11 per second neutron source. No additional calibrations required for individual measurements. System is not geometry dependent.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 12 Burnup (MWD/MTHM)
Performance Goal: +/- Factor of 3 to 10
Meets Performance Goal: Yes
Phenomena Measured: Prompt fission products. Coincident gamma rays.
Additional Information Required:

BOL Fissile Content

Measurement Uncertainty: 50%
Measurement Duration: 20 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: Duration is based on an 1E11 per second neutron source. No additional calibrations required for individual measurements. System is not geometry dependent.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 13 EOL U-234 and U-236 content (Post-irradiation)
Performance Goal: No specific limit at this time.
Meets Performance Goal: Yes
Phenomena Measured: Prompt fission products. Coincident gamma rays.
Additional Information Required: None

Measurement Uncertainty: 20%
Measurement Duration: 20 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: Duration is based on an 1E11 per second neutron source. No additional calibrations required for individual measurements. System is not geometry dependent.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 14	Gross gamma flux
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	Prompt fission products. Coincident gamma rays.
Additional Information Required:	None

Measurement Uncertainty:	20%
Measurement Duration:	20 min.
Sensitivity to Measurement Duration:	Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Duration is based on an 1E11 per second neutron source. No additional calibrations required for individual measurements. System is not geometry dependent.

Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	

SNF Property # 15	Gross neutron flux
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	Prompt fission products. Coincident gamma rays.
Additional Information Required:	None

Measurement Uncertainty:	20%
Measurement Duration:	20 min.
Sensitivity to Measurement Duration:	Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Duration is based on an 1E11 per second neutron source. No additional calibrations required for individual measurements. System is not geometry dependent.

Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	

SNF Property # 16 Free Liquids in Canistered SNF
Performance Goal: 0.2 kg to 1.3 kg total water
Meets Performance Goal: Yes
Phenomena Measured: Detect Hydrogen
Additional Information Required: None

Measurement Uncertainty: %
Measurement Duration: 20 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: Duration is based on an 1E11 per second neutron source. No additional calibrations required for individual measurements. System is not geometry dependent.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 17 Moisture content of fuel item (g)
Performance Goal: No specific limit at this time.
Meets Performance Goal: Yes
Phenomena Measured: Detect Hydrogen
Additional Information Required: None

Measurement Uncertainty: %
Measurement Duration: 20 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: Duration is based on an 1E11 per second neutron source. No additional calibrations required for individual measurements. System is not geometry dependent.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 18	Moisture content of loaded canister (g)
Performance Goal:	0.2 kg to 1.3 kg total water
Meets Performance Goal:	Yes
Phenomena Measured:	Detect Hydrogen
Additional Information Required:	None
Measurement Uncertainty:	%
Measurement Duration:	20 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Duration is based on an 1E11 per second neutron source. No additional calibrations required for individual measurements. System is not geometry dependent.
Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	
SNF Property # 19	Pu-238 & Pu-240 content (weight %) (Post-Irradiation)
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	Prompt fission products. Coincident gamma rays.
Additional Information Required:	None
Measurement Uncertainty:	20%
Measurement Duration:	20 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Duration is based on an 1E11 per second neutron source. No additional calibrations required for individual measurements. System is not geometry dependent.
Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	

SNF Property # 20

Ac227;Am241/2m/3;C14;Cl36;Cm244/5/6;Cs135;Nb93m/94;Ni59/63;Pa231;Pb210;Pd107;Pu242;Ra226/8;Se79;Sm151;Sn126;Th-229/230;Zr93 (Ci/package)

Performance Goal:

No specific limit at this time.

Meets Performance Goal:

Yes

Phenomena Measured:

Prompt fission products. Coincident gamma rays.

Additional Information Required:

None

Measurement Uncertainty:

30%

Measurement Duration:

20 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

Duration is based on an 1E11 per second neutron source. No additional calibrations required for individual measurements. System is not geometry dependent.

Only some radionuclides can be measured, the others must be derived.

Limiting SNF Attribute # 1

No Limitation

Attribute Value:

No Limitation

Limiting Attribute Comment:**SNF Property # 21**

U-232 content (Post-irradiation) (ppm, if applicable)

Performance Goal:

No specific limit at this time.

Meets Performance Goal:

Yes

Phenomena Measured:

Prompt fission products. Coincident gamma rays.

Additional Information Required:

None

Measurement Uncertainty:

20%

Measurement Duration:

20 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

Duration is based on an 1E11 per second neutron source. No additional calibrations required for individual measurements. System is not geometry dependent.

Limiting SNF Attribute # 1

No Limitation

Attribute Value:

No Limitation

Limiting Attribute Comment:

System Report

System Name:**Description:****Neutron Activation/Gamma Detection**

This system was developed to measure the ²³⁵U content of new commercial fuel elements, and a modification was proposed (but never used) for measuring the ²³⁵U content of ROVER fuel and scrap. It operates on the principal of thermal neutron induced fission of the fissile material in the spent fuel using a ²⁵²Cf source and detection of short lived, high-energy gamma-emitting fission products with a large germanium spectrometer. The system can measure total fissile content to a precision and accuracy of 1%. Its limitations are that it measures total fissile content, and while in theory it can measure the difference between ²³⁹Pu and ²³⁵U, this would not be expected to be possible with any high degree of reliability in real-world mixtures of the two in spent fuel. This system also must be experimentally calibrated for each different fuel geometry, although not necessarily for different starting fuel compositions. High concentrations of poisons in the fuel could affect the accuracy of the measurements by absorbing a significant fraction of the neutron flux. An adaptable geometry design would be required to accommodate all different types of spent fuel. The system only measure total fissile mass; it does not measure isotopic composition or burnup. The instrument is suitable for all types of spent fuel.

SNF Experience:**Description of SNF Experience:**

Proof of Principle.

Has been demonstrated on new fuel, and been shown that it will also work for spent fuel.

Non-SNF Experience:**Description of Non-SNF Experience:**

Field Deployed for Multiple SNF/Non-SNF.

Funded Development:

Completely developed and operational for new fuel. Unfunded for application to spent fuel

Operating Environment:

Dry Cell.

R and D Costs:

\$1M to \$5M

Procurement Costs:

\$1M to \$5M

In-Cell Space:

10 to 50 sq. ft.

Out-Cell Space:

10 to 50 sq. ft.

O and M Personnel:

<1 FTE

R and D Schedule:

1 to 2 yrs

Deployment Schedule:

1 to 2 yrs

Measurable Configurations:

Bare Fuel and Canisters

Additional Information:

SNF Property # 1	Total Fissile Material in Disposable Canister
Performance Goal:	Key Property: +/- 70%
Meets Performance Goal:	Yes
Phenomena Measured:	Measures the high energy gamma rays emitted by short-lived fission fragments following induced fission by thermal neutron irradiation
Additional Information Required:	None
Measurement Uncertainty:	1%
Measurement Duration:	2 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Only requires a few standards of each TYPE of fuel. The more types of fuel, the more standards are required.
Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	
SNF Property # 2	Burnup (MWD/MTHM)
Performance Goal:	+/- Factor of 3 to 10
Meets Performance Goal:	Yes
Phenomena Measured:	Measures the high energy gamma rays emitted by short-lived fission fragments following induced fission by thermal neutron irradiation
Additional Information Required:	BOL Fissile Content
Measurement Uncertainty:	1%
Measurement Duration:	2 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Only requires a few standards of each TYPE of fuel. The more types of fuel, the more standards are required.
Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	

System Report

System Name:	Noble Gas Collection and Analysis System for Fuel Rod Cladding Integrity Check
Description:	This system (can be automated) collects and analyzes noble gases (85Kr) expected emanating from fuel rods that cracked.
SNF Experience:	None.
Description of SNF Experience:	
Non-SNF Experience:	Field Deployed for Single SNF/Non-SNF.
Description of Non-SNF Experience:	We have developed the world's only automated radioxenon sampler-analyzer at PNNL. We may be able to modify the technology to monitor 85Kr. A system was successfully field deployed for several months in 1997.
Funded Development:	DOE NN-20 Comprehensive Test Ban Treaty R &D program
Operating Environment:	Dry Cell.
R and D Costs:	\$200K to \$1M
Procurement Costs:	<\$200K
In-Cell Space:	10 to 50 sq. ft.
Out-Cell Space:	<10 sq. ft.
O and M Personnel:	1 to 2 FTEs
R and D Schedule:	1 to 2 yrs
Deployment Schedule:	2 to 4 yrs
Measurable Configurations:	Canister
Additional Information:	
SNF Property # 1	Requirements that canisters be sealed
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	85Kr air concentration
Additional Information Required:	None
Measurement Uncertainty:	N.A. %
Measurement Duration:	480 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Minimum detectable activity 1 to 10 mBq/m3
Limiting SNF Attribute # 1	Gross gamma radiation (based on PWR assembly)
Attribute Value:	1E+09 to 1E+11 photons/assy/sec
Attribute Value:	1E+11 to 1E+13 photons/assy/sec
Attribute Value:	1E+13 to 1E+15 photons/assy/sec
Attribute Value:	>1E+15 photons/assy/sec
Limiting Attribute Comment:	Can be located remotely, also

System Report

System Name:

Description:

Noise Analysis Measurement System

Active neutron interrogation system that correlates a neutron detector response with an interrogating neutron source. The measurement is equivalent to a pulsed neutron measurement. The measurement involves the use of a Fourier analyzer to acquire the signals from the neutron source and one or more neutron detectors. The responses of the neutron detectors are correlated with the source events in the frequency domain. Fourier processing is used because of the increased speed in performing such measurements in the frequency domain. Neutrons from the source interact with the fissile system and produce fission neutrons. These fission neutrons interact further with the system until their progeny reach the detectors. The correlation between the source and the detector is directly dependent on the total amount of fissile material. A change in the fissile mass produces a change in the induced fission rate and hence would produce a change in the source-detector correlation. The magnitude of the source-detector correlation function is independent of the inherent neutron and gamma ray sources. These inherent sources only affect the measurement time required to obtain a desired convergence of the source-detector correlation function. The system also measures the detector auto spectra and the detector-detector cross spectra that are equivalent to the single-detector Rossi- α and two-detector Rossi- α measurements respectively. Therefore, the measurement system could be used in an active mode using a neutron source or could be applied passively without the use of a neutron source.

Method was originally developed to determine the subcriticality of fissile systems. A particular ratio of spectral indices has been shown to be directly related to k-eff. In the past, formulas were used to relate the measured spectral ratio to k-eff. Now, Monte Carlo methods are used to directly calculate the measured spectral indices and determine the k-eff using the measured and calculated spectral indices.

SNF Experience:

Description of SNF Experience:

Laboratory Development.

A variety of measurements have been performed with this system for subcriticality of fresh fuel. Recently, subcriticality measurements have been performed with spent research reactor fuel elements. These measurements were concerned with determining the change in reactivity of the spent fuel, but these measurements do indicate the change in the signatures for different spent nuclear fuel.

Non-SNF Experience:

Description of Non-SNF Experience:

Field Deployed for Multiple SNF/Non-SNF.

We have performed measurements at various DOE sites with both uranium metal and plutonium metal fissile systems ranging from a few grams to 5 MT of HEU. Measurements have been performed on uranium fluoride, uranyl nitrate, and plutonium-uranium solution systems. These measurements were performed to address the use of this method for criticality safety. However, the method could be extended to perform non-destructive assay of fissile material because large changes have been observed large changes in our measured signatures for small changes in the fissile systems.

Currently we have no funding to develop the application of this method for assay of SNF.

Funded Development:

Operating Environment:

Underwater and Dry Cell.

R and D Costs:

\$1M to \$5M

Procurement Costs:

\$200K to \$1M

In-Cell Space:

<10 sq. ft.

Out-Cell Space:

<10 sq. ft.

O and M Personnel:

1 to 2 FTEs

R and D Schedule:

1 to 2 yrs

Deployment Schedule:

1 to 2 yrs

Measurable Configurations:
Additional Information:

Bare Fuel and Canisters
This system itself is quite general. The specific application would determine the number and type of detectors that would be used and the geometrical configuration of the source and detectors. Feasibility studies have been + performed that indicate this system could be used to assay spent fuel assemblies by scanning LWR elements. Measurements could also be made to quantify the fissile mass of research reactor fuel elements without necessarily scanning the elements.

SNF Property #1

Performance Goal:

Meets Performance Goal:

Phenomena Measured:

Pu-239 content (weight % & g) (Post-Irradiation)

Key Property: +/- 70%

Yes

Measures the amount of induced fission in the system and hence the total fissile mass.

Additional Information Required:

BOL Enrichment

Measurement Uncertainty:

5%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

The measurement time and uncertainty depends on the source strength and the number of detectors that are used in the measurements.

SNF Property # 2

Performance Goal:

Meets Performance Goal:

Phenomena Measured:

Total Fissile Material in Disposable Canister

Key Property: +/- 70%

Yes

Measures the amount of induced fission in the system and hence the total fissile mass.

Additional Information Required:

None

Measurement Uncertainty:

5%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

The measurement time and uncertainty depends on the source strength and the number of detectors that are used in the measurements.

Limiting SNF Attribute # 1

No Limitation

Attribute Value:

No Limitation

Limiting Attribute Comment:

SNF Property # 3**Performance Goal:****Meets Performance Goal:****Phenomena Measured:**

U-233 content, (Post-irradiation) (weight % & g)

Key Property: +/- 70%

Yes

Measures the amount of induced fission in the system and hence the total fissile mass.

Additional Information Required:

BOL Enrichment

Measurement Uncertainty:

5%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

The measurement time and uncertainty depends on the source strength and the number of detectors that are used in the measurements.

SNF Property # 4**Performance Goal:****Meets Performance Goal:****Phenomena Measured:**

U-235 content, (Post-irradiation) (weight % & g)

Key Property: +/- 70%

Yes

Measures the amount of induced fission in the system and hence the total fissile mass.

Additional Information Required:

BOL Enrichment

Measurement Uncertainty:

5%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

The measurement time and uncertainty depends on the source strength and the number of detectors that are used in the measurements.

SNF Property # 5**Performance Goal:****Meets Performance Goal:****Phenomena Measured:**

Total Pu content (post-irradiation) (g)

+/- 70%

Yes

Measures the amount of induced fission in the system and hence the total fissile mass.

Additional Information Required:

BOL Enrichment

Measurement Uncertainty:

5%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

The measurement time and uncertainty depends on the source strength and the number of detectors that are used in the measurements.

SNF Property # 6	Burnup (MWD/MTHM)
Performance Goal:	+/- Factor of 3 to 10
Meets Performance Goal:	Yes
Phenomena Measured:	Measures the amount of induced fission in the system and hence the total fissile mass.

Additional Information Required:

BOL Fissile Content

Measurement Uncertainty:	5%
Measurement Duration:	60 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	The measurement time and uncertainty depends on the source strength and the number of detectors that are used in the measurements.

Limiting SNF Attribute # 1 No Limitation

Attribute Value: No Limitation

Limiting Attribute Comment:

SNF Property # 7	Gross neutron flux
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	
Additional Information Required:	None

Measurement Uncertainty:	5%
Measurement Duration:	60 min.
Sensitivity to Measurement Duration:	Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	The detector count rate and auto correlation functions are direct measures of the neutron flux emanating from the fissile system.

Limiting SNF Attribute # 1 No Limitation

Attribute Value: No Limitation

Limiting Attribute Comment:

SNF Property # 8	Pu-238 & Pu-240 content (weight %) (Post-Irradiation)
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	Measures the amount of induced fission in the system and hence the total fissile mass.

Additional Information Required:	BOL Enrichment
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Measurement Uncertainty:	5%
Measurement Duration:	60 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	The measurement time and uncertainty depends on the source strength and the number of detectors that are used in the measurements.

SNF Property # 9	k-eff
Performance Goal:	< 0.95 after bias/uncertainty
Meets Performance Goal:	Yes
Phenomena Measured:	Noise analysis measurements can be used to determine the k-eff of fissile systems. A certain ratio of frequency spectra are obtained from the measurement that is linearly related to k-eff. Monte Carlo calculations are used to compute the spectral ratio and can be used to determine the experimental k-eff.

Additional Information Required:	None
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Measurement Uncertainty:	3%
Measurement Duration:	60 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	The determination of k-eff via noise analysis techniques does not require a calibration measurement. As with all measurements used to interpret k-eff a model must be used that relates the measured parameters to k-eff. In this case a Monte Carlo simulation of the measurement is performed to determine k-eff. However, if necessary, point kinetics expressions can be used to equate the measured parameters to k-eff.

Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	

System Report

System Name:**Description:****Nuclear Magnetic Resonance & Imaging System**

The toroid cavity detector is a nuclear magnetic resonance probe that is different from other more conventional electromagnetic detectors in that it produces a gradient in the radio frequency magnetic field that it generates. This feature has two significant consequences. First, the sensitivity of the toroid cavity is radially distributed, with the greatest sensitivity near the central axis of the device. This allows detection of water and hydrogen nuclei in a sample that is available in a limited quantity. Secondly, concentric annular regions of a sample contained in the toroid cavity exchange energy with the resonator circuit at different rates. Thus, by analyzing energy transfer rates in a toroid cavity it is possible to obtain a radial spatial mapping of the different nuclear constituents in a cylindrical container or canister.

SNF Experience:**Description of SNF Experience:****Non-SNF Experience:****Description of Non-SNF Experience:**

None.

Laboratory Development.

This program focuses on studies to evaluate nuclear magnetic resonance (NMR) spectroscopy and magnetic resonance imaging (MRI) for detecting, quantifying, and monitoring moisture, hydrogen, and other magnetically active nuclei (^3H , ^3He , ^{235}U , ^{239}Pu , ^{241}Pu) in spent nuclear fuels and packaging materials. The detection of moisture by using a toroid cavity NMR imager has been demonstrated for SiO_2 and UO_2 powders under ambient conditions. The total moisture was quantified by means of ^1H NMR detection of H_2O with a sensitivity approaching 100 ppm. In addition, the MRI technique that was used to determine the moisture distribution also enabled investigators to discriminate between bulk and stationary water sorbed on the particles. This imaging feature is unavailable in any other nondestructive assay (NDA) technique. Following the initial success of this activity, the NMR detector volume was scaled up from the original design by a factor of 2000. The capacity of this detector exceeds the size specified for DOE-STD-3013-96 containers, used to package Pu and Pu-bearing materials.

Funded Development:**Operating Environment:****R and D Costs:****Procurement Costs:****In-Cell Space:****Out-Cell Space:****O and M Personnel:****R and D Schedule:****Deployment Schedule:****Measurable Configurations:****Additional Information:**

Not funded for SNF.

Dry Cell.

\$1M to \$5M

\$1M to \$5M

<10 sq. ft.

50 to 100 sq. ft.

<1 FTE

2 to 4 yrs

<1 yr

Bare Fuel and Canisters

SNF Property # 1
Performance Goal: Free Liquids in Canistered SNF
0.2 kg to 1.3 kg total water
Meets Performance Goal: Yes
Phenomena Measured: Measures chemical shift to distinguish between water and hydrogen nuclei obtained from radiofrequency obtained from an antenna signal.
Additional Information Required: None

Measurement Uncertainty: 3%
Measurement Duration: 60 min.
Sensitivity to Measurement Duration: Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments:
Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 2
Performance Goal: Moisture content of fuel item (g)
No specific limit at this time.
Meets Performance Goal: Yes
Phenomena Measured: Measures chemical shift to distinguish between water and hydrogen nuclei obtained from radiofrequency obtained from an antenna signal.
Additional Information Required: None

Measurement Uncertainty: 3%
Measurement Duration: 60 min.
Sensitivity to Measurement Duration: Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments:
Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 3

Performance Goal:

Meets Performance Goal:

Phenomena Measured:

Moisture content of loaded canister (g)

0.2 kg to 1.3 kg total water

Yes

Measures chemical shift to distinguish between water and hydrogen nuclei obtained from radiofrequency obtained from an antenna signal.

Additional Information Required:

None

Measurement Uncertainty:

3%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is not improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

Limiting SNF Attribute # 1

No Limitation

Attribute Value:

No Limitation

Limiting Attribute Comment:

System Report

System Name:**Description:****Passive Neutron Detection**

This system was used to measure the plutonium isotopic composition in spent N-Reactor fuel elements underwater by measuring the passive neutrons emitted from the fuel. Since the system was used to measure isotopic composition, it also determined, by definition, the burnup and the amount of plutonium present. Since the system was limited to measuring total passive neutron flux; all neutron emitters (including curium) contributed to the signal. The system must be calibrated, by laboratory analysis of measured fuel, to relate the measured neutron flux to the isotopic composition. This calibration should remove the effects of curium. It is also necessary to know the starting fuel composition, and to calibrate the system for each different starting fuel composition. The system was specifically designed for N-Reactor fuel element geometry and would need to be reconfigured into an adaptable design which could accommodate many different fuel element geometries. The system does not measure ²³⁵U; it only measures neutrons. Calibration will provide the isotopic composition of those isotopes contributing to the neutron flux, which can be related to the burnup. If the original fuel composition is known, the remaining ²³⁵U can be inferred, but it is not directly measurable. Precision measurements on a single fuel element were 3%. Accuracy on a suite of fuel elements was 0.05%.

SNF Experience:**Description of SNF Experience:**

Field Deployed for Single SNF/Non-SNF.

The system was able to determine the isotopic composition of the plutonium in 160,000 spent fuel elements in the course of 7 months at an accuracy of 0.05%.

Non-SNF Experience:**Description of Non-SNF Experience:****Funded Development:**

Laboratory Development.

Can also be applied to measuring the plutonium content of wastes.

Development and use for sorting spent N-reactor fuel elements according to isotopic composition of the plutonium present in the elements has been completed.

Operating Environment:**R and D Costs:****Procurement Costs:****In-Cell Space:****Out-Cell Space:****O and M Personnel:****R and D Schedule:****Deployment Schedule:****Measurable Configurations:****Additional Information:**

Underwater and Dry Cell.

\$1M to \$5M

\$1M to \$5M

50 to 100 sq. ft.

10 to 50 sq. ft.

<1 FTE

1 to 2 yrs

<1 yr

Bare Fuel

SNF Property # 1	Pu-239 content (weight % & g) (Post-Irradiation)
Performance Goal:	Key Property: +/- 70%
Meets Performance Goal:	Yes
Phenomena Measured:	Measures total passive neutron flux emitted by the spent fuel element
Additional Information Required:	BOL Enrichment BOL Fissile Content

Measurement Uncertainty:	3%
Measurement Duration:	2 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	

Limiting SNF Attribute # 1 Fuel unit poison material

Attribute Value: Boron

Attribute Value: Cadmium

Attribute Value: Erbium

Attribute Value: Gadolinium

Limiting Attribute Comment:

SNF Property # 2	Total Pu content (post-irradiation) (g)
Performance Goal:	+/- 70%
Meets Performance Goal:	Yes
Phenomena Measured:	
Additional Information Required:	BOL Enrichment BOL Fissile Content

Measurement Uncertainty:	3%
Measurement Duration:	2 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	

Limiting SNF Attribute # 1 Fuel unit poison material

Attribute Value: Boron

Attribute Value: Cadmium

Attribute Value: Erbium

Attribute Value: Gadolinium

Limiting Attribute Comment:

SNF Property # 3	Burnup (MWD/MTHM)	
Performance Goal:	+/- Factor of 3 to 10	
Meets Performance Goal:	Yes	
Phenomena Measured:		
Additional Information Required:		BOL Enrichment BOL Fissile Content

Measurement Uncertainty:	3%
Measurement Duration:	2 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	

Limiting SNF Attribute # 1	Fuel unit poison material
Attribute Value:	Boron
Attribute Value:	Cadmium
Attribute Value:	Erbium
Attribute Value:	Gadolinium

Limiting Attribute Comment:

SNF Property # 4	Gross neutron flux
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	
Additional Information Required:	None

Measurement Uncertainty:	3%
Measurement Duration:	2 min.
Sensitivity to Measurement Duration:	Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	

Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation

Limiting Attribute Comment:

SNF Property # 5

Performance Goal:

Meets Performance Goal:

Phenomena Measured:

Additional Information Required:

Pu-238 & Pu-240 content (weight %) (Post-Irradiation)

No specific limit at this time.

Yes

BOL Enrichment

BOL Fissile Content

Measurement Uncertainty:

3%

Measurement Duration:

2 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

Limiting SNF Attribute # 1 Fuel unit poison material

Attribute Value: Boron

Attribute Value: Cadmium

Attribute Value: Erbium

Attribute Value: Gadolinium

Limiting Attribute Comment:

System Report

System Name:**Description:****Research Reactor Fuel Counter**

This is an underwater version of an active well coincidence counter. The RRFC includes two Am/Li neutron sources to actively interrogate a fuel assembly. It estimates U-235 mass by measuring induced coincident fission neutrons, and it distinguishes true coincident events from singles (such as alpha, n reactions) using shift register electronics.

SNF Experience:**Description of SNF Experience:**

Field Deployed for Multiple SNF/Non-SNF.

Numerous measurements have been completed on domestic and foreign HEU research reactor fuel assemblies. Tests conducted at the SRS Receiving Basin for Off-site Fuels will be described at the ANS Topical Meeting on spent nuclear fuels in Charleston, SC (Sept. 98). As presently configured, the device does not allow both passive measurements and active interrogation. This limits accuracy since the fuels emit significant (alpha, n), spontaneous fission and self-interrogation neutrons above those induced by the Am/Li sources.

Non-SNF Experience:**Description of Non-SNF Experience:**

Field Deployed for Multiple SNF/Non-SNF.

AWCCs have been used in HEU safeguards applications on unirradiated materials for approximately two decades.

Numerous descriptions can be found in safeguards literature (INMM).

Funded Development:**Operating Environment:****R and D Costs:****Procurement Costs:****In-Cell Space:****Out-Cell Space:****O and M Personnel:****R and D Schedule:****Deployment Schedule:****Measurable Configurations:****Additional Information:**

Funded by OSS not by SNF.

Underwater.

<\$200K

\$200K to \$1M

<10 sq. ft.

<10 sq. ft.

<1 FTE

None

<1 yr

Bare Fuel

SNF Property # 1**Performance Goal:****Meets Performance Goal:****Phenomena Measured:**

Pu-239 content (weight % & g) (Post-Irradiation)

Key Property: +/- 70%

Yes

Measures coincident fission neutrons in a high field of singles neutrons and gamma rays.

Additional Information Required:

BOL Enrichment

Burnup

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:

25%

Measurement Duration:

10 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

Additional information on the fuel geometry is also required.

If combined with gamma-ray isotopics, then Pu-239 can be determined. It is expected that 10 calibration standards may be required. Additional information on gamma ray isotopics is also required. Statistical precision improves with increased measurement time, but other uncertainties dominate. To improve accuracy, standards would be needed for each fuel type, or separate Monte-Carlo modeling of each type. Presently, a single MTR fuel standard is used.

SNF Property # 2**Performance Goal:****Meets Performance Goal:****Phenomena Measured:**

Total Fissile Material in Disposable Canister

Key Property: +/- 70%

Yes

Measures coincident fission neutrons in a high field of singles neutrons and gamma rays.

Additional Information Required:

None

Measurement Uncertainty:

25%

Measurement Duration:

10 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

Statistical precision improves with increased measurement time, but other uncertainties dominate. To improve accuracy, standards would be needed for each fuel type, or separate Monte-Carlo modeling of each type. Presently, a single MTR fuel standard is used.

Limiting SNF Attribute # 1

No Limitation

Attribute Value:

No Limitation

Limiting Attribute Comment:

SNF Property # 3**Performance Goal:****Meets Performance Goal:****Phenomena Measured:**

U-233 content, (Post-irradiation) (weight % & g)

Key Property: +/- 70%

Yes

Measures coincident fission neutrons in a high field of singles neutrons and gamma rays.

Additional Information Required:

BOL Enrichment

Burnup

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:

25%

Measurement Duration:

10 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

Additional information on gamma ray isotopics is also be required. Statistical precision improves with increased measurement time, but other uncertainties dominate. To improve accuracy, standards would be needed for each fuel type, or separate Monte-Carlo modeling of each type. Presently, a single MTR fuel standard is used.

SNF Property # 4**Performance Goal:****Meets Performance Goal:****Phenomena Measured:**

U-235 content, (Post-irradiation) (weight % & g)

Key Property: +/- 70%

Yes

Measures coincident fission neutrons in a high field of singles neutrons and gamma rays.

Additional Information Required:

BOL Enrichment

Burnup

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:

25%

Measurement Duration:

10 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

Additional information on gamma ray isotopics is also be required. Statistical precision improves with increased measurement time, but other uncertainties dominate. To improve accuracy, standards would be needed for each fuel type, or separate Monte-Carlo modeling of each type. Presently, a single MTR fuel standard is used.

SNF Property # 5**Performance Goal:****Meets Performance Goal:****Phenomena Measured:**

Total Pu content (post-irradiation) (g)

+/- 70%

Yes

Measures coincident fission neutrons in a high field of singles neutrons and gamma rays.

Additional Information Required:

BOL Enrichment

Burnup

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:

25%

Measurement Duration:

10 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

Gamma ray isotopics are also required. Statistical precision improves with increased measurement time, but other uncertainties dominate. To improve accuracy, standards would be needed for each fuel type, or separate Monte-Carlo modeling of each type. Presently, a single MTR fuel standard is used.

SNF Property # 6**Performance Goal:****Meets Performance Goal:****Phenomena Measured:**

Burnup (MWD/MTHM)

+/- Factor of 3 to 10

Yes

Measures coincident fission neutrons in a high field of singles neutrons and gamma rays.

Additional Information Required:

BOL Enrichment

BOL Fissile Content

Measurement Uncertainty:

25%

Measurement Duration:

10 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:**Limiting SNF Attribute # 1** No Limitation**Attribute Value:** No Limitation**Limiting Attribute Comment:**

SNF Property # 7	Gross neutron flux
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	Measures coincident fission neutrons in a high field of singles neutrons and gamma rays.
Additional Information Required:	None

Measurement Uncertainty:	25%
Measurement Duration:	10 min.
Sensitivity to Measurement Duration:	Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	
Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	

SNF Property # 8	Pu-238 & Pu-240 content (weight %) (Post-Irradiation)
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	Measures coincident fission neutrons in a high field of singles neutrons and gamma rays.
Additional Information Required:	BOL Enrichment
	Burnup Other (Identified in Property Measurement Comments)

Measurement Uncertainty:	25%
Measurement Duration:	10 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	10 to 50 Standards.
Property Measurement Comments:	Additional information on gamma ray isotopics is also needed. Statistical precision improves with increased measurement time, but other uncertainties dominate. To improve accuracy, standards would be needed for each fuel type, or separate Monte-Carlo modeling of each type. Presently, a single MTR fuel standard is used.

System Report

System Name:**Description:****Resonance Transmission Analysis System**

The system is based on neutron transmission through a sample at different neutron energies. A reactor beam is filtered and transmitted through the sample. By changing the filters, resonances of specific isotopes can be isolated (such as Pu-239). By measuring the transmitted flux through the various resonances the amount of the isotopes in a sample can be determined.

Laboratory Development.

SNF Experience:**Description of SNF Experience:****Non-SNF Experience:****Description of Non-SNF Experience:****Funded Development:**

Proof of Principle.

Funding was only provided for proof-of-principle experiments. No funding has been provided for lab development.

Operating Environment:**R and D Costs:****Procurement Costs:****In-Cell Space:****Out-Cell Space:****O and M Personnel:****R and D Schedule:****Deployment Schedule:****Measurable Configurations:****Additional Information:**

Dry Cell.

\$200K to \$1M

\$200K to \$1M

10 to 50 sq. ft.

>100 sq. ft.

1 to 2 FTEs

1 to 2 yrs

1 to 2 yrs

Bare Fuel and Canisters

The system requires a reactor beam and Plutonium detector. Previous tests on the system with small samples (26 grams) indicate that the system can determine small amounts of Pu-239 (less than 0.1 wt%) with accuracies in the range of a few percent.

SNF Property # 1**Performance Goal:****Meets Performance Goal:****Phenomena Measured:****Additional Information Required:**

Pu-239 content (weight % & g) (Post-Irradiation)

Key Property: +/- 70%

Yes

Attenuation of neutrons at different energies by the sample

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:**Measurement Duration:****Sensitivity to Measurement Duration:****Calibration Standards Required:****Property Measurement Comments:**

15%

60 min.

Uncertainty is improved by increasing measurement duration.

10 to 50 Standards.

Necessary parameters for a measurement include the total mass of the sample and the physical geometry of the sample.

Limiting SNF Attribute # 1**Attribute Value:****Limiting Attribute Comment:**

No Limitation

No Limitation

SNF Property # 2**Performance Goal:****Meets Performance Goal:****Phenomena Measured:****Additional Information Required:**

Total Fissile Material in Disposable Canister

Key Property: +/- 70%

Yes

Attenuation of neutrons at different energies by the sample

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:

15%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

10 to 50 Standards.

Property Measurement Comments:

Necessary parameters for a measurement include the total mass of the sample and the physical geometry of the sample.

Limiting SNF Attribute # 1

No Limitation

Attribute Value: *No Limitation***Limiting Attribute Comment:****SNF Property # 3****Performance Goal:****Meets Performance Goal:****Phenomena Measured:****Additional Information Required:**

U-233 content, (Post-irradiation) (weight % & g)

Key Property: +/- 70%

Yes

Attenuation of neutrons at different energies by the sample

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:

15%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

10 to 50 Standards.

Property Measurement Comments:

Necessary parameters for a measurement include the total mass of the sample and the physical geometry of the sample.

Limiting SNF Attribute # 1

No Limitation

Attribute Value: *No Limitation***Limiting Attribute Comment:**

SNF Property # 4**Performance Goal:****Meets Performance Goal:****Phenomena Measured:****Additional Information Required:**

U-235 content, (Post-irradiation) (weight % & g)

Key Property: +/- 70%

Yes

Attenuation of neutrons at different energies by the sample

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:

15%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

10 to 50 Standards.

Property Measurement Comments:

Necessary parameters for a measurement include the total mass of the sample and the physical geometry of the sample.

Limiting SNF Attribute # 1

No Limitation

Attribute Value: *No Limitation***Limiting Attribute Comment:****SNF Property # 5****Performance Goal:****Meets Performance Goal:****Phenomena Measured:****Additional Information Required:**

U-238 content (Post-irradiation)

Key Property: No limit at this time.

Yes

Attenuation of neutrons at different energies by the sample

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:

15%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

10 to 50 Standards.

Property Measurement Comments:

Necessary parameters for a measurement include the total mass of the sample and the physical geometry of the sample.

Limiting SNF Attribute # 1

No Limitation

Attribute Value: *No Limitation***Limiting Attribute Comment:**

SNF Property # 6**Performance Goal:****Meets Performance Goal:****Phenomena Measured:****Additional Information Required:**

Enrichment (post-irradiation) (% U-235)

Key Property: +/- 10%

Yes

Attenuation of neutrons at different energies by the sample

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:

%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

10 to 50 Standards.

Property Measurement Comments:

Necessary parameters for a measurement include the total mass of the sample and the physical geometry of the sample.

Limiting SNF Attribute # 1

No Limitation

Attribute Value:

No Limitation

Limiting Attribute Comment:**SNF Property # 7****Performance Goal:****Meets Performance Goal:****Phenomena Measured:****Additional Information Required:**

Total U content (post-irradiation) (g)

+/- 70%

Yes

Attenuation of neutrons at different energies by the sample

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:

15%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

10 to 50 Standards.

Property Measurement Comments:

Necessary parameters for a measurement include the total mass of the sample and the physical geometry of the sample.

Limiting SNF Attribute # 1

No Limitation

Attribute Value:

No Limitation

Limiting Attribute Comment:

SNF Property # 8**Performance Goal:****Meets Performance Goal:****Phenomena Measured:****Additional Information Required:**

Total Pu content (post-irradiation) (g)

+/- 70%

Yes

Attenuation of neutrons at different energies by the sample

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:

15%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

10 to 50 Standards.

Property Measurement Comments:

Necessary parameters for a measurement include the total mass of the sample and the physical geometry of the sample.

Limiting SNF Attribute # 1

No Limitation

Attribute Value:

No Limitation

Limiting Attribute Comment:**SNF Property # 9****Performance Goal:****Meets Performance Goal:****Phenomena Measured:****Additional Information Required:**

Burnup (MWD/MTHM)

+/- Factor of 3 to 10

Yes

Attenuation of neutrons at different energies by the sample

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:

15%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

10 to 50 Standards.

Property Measurement Comments:

Necessary parameters for a measurement include the total mass of the sample and the physical geometry of the sample.

Limiting SNF Attribute # 1

No Limitation

Attribute Value:

No Limitation

Limiting Attribute Comment:

SNF Property # 10	Concentration and total masses of neutron absorbers (g/m ³ & g)
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	Attenuation of neutrons at different energies by the sample
Additional Information Required:	

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:	5%
Measurement Duration:	60 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	10 to 50 Standards.
Property Measurement Comments:	Necessary parameters for a measurement include the total mass of the sample and the physical geometry of the sample.

Limiting SNF Attribute # 1 No Limitation

Attribute Value: No Limitation

Limiting Attribute Comment:

SNF Property # 11	Free Liquids in Canistered SNF
Performance Goal:	0.2 kg to 1.3 kg total water
Meets Performance Goal:	Yes
Phenomena Measured:	Attenuation of neutrons at different energies by the sample
Additional Information Required:	

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:	1%
Measurement Duration:	60 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	10 to 50 Standards.
Property Measurement Comments:	Necessary parameters for a measurement include the total mass of the sample and the physical geometry of the sample.

Limiting SNF Attribute # 1 No Limitation

Attribute Value: No Limitation

Limiting Attribute Comment:

SNF Property # 12**Performance Goal:****Meets Performance Goal:****Phenomena Measured:****Additional Information Required:**

Moisture content of fuel item (g)

No specific limit at this time.

Yes

Attenuation of neutrons at different energies by the sample

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:

1%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

10 to 50 Standards.

Property Measurement Comments:

Necessary parameters for a measurement include the total mass of the sample and the physical geometry of the sample.

Limiting SNF Attribute # 1

No Limitation

Attribute Value:

No Limitation

Limiting Attribute Comment:**SNF Property # 13****Performance Goal:****Meets Performance Goal:****Phenomena Measured:****Additional Information Required:**

Moisture content of loaded canister (g)

0.2 kg to 1.3 kg total water

Yes

Attenuation of neutrons at different energies by the sample

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:

1%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

10 to 50 Standards.

Property Measurement Comments:

Necessary parameters for a measurement include the total mass of the sample and the physical geometry of the sample.

Limiting SNF Attribute # 1

No Limitation

Attribute Value:

No Limitation

Limiting Attribute Comment:

SNF Property # 14

Performance Goal:

Meets Performance Goal:

Phenomena Measured:

Additional Information Required:

Pu-238 & Pu-240 content (weight %) (Post-Irradiation)

No specific limit at this time.

Yes

Attenuation of neutrons at different energies by the sample

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:

15%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

10 to 50 Standards.

Property Measurement Comments:

Necessary parameters for a measurement include the total mass of the sample and the physical geometry of the sample.

Limiting SNF Attribute # 1

No Limitation

Attribute Value:

No Limitation

Limiting Attribute Comment:

System Report

System Name:**Description:****Shielded Measurement System Phase 1**

Combines gross gamma-ray and gross neutron measurement instruments with a scanning system within a shielded enclosure to allow measurement of items without removing them from a hot cell.

SNF Experience:**Description of SNF Experience:**

Proof of Principle.

Several EBR-II spent fuel assemblies were measured using a gross neutron measurement system installed in a shield ring. Burnup profiles were obtained allowing identification of different fuel types. Total neutron count rates were found to correlate with burnup, indicating that Pu-240 was being measured.

None.

Non-SNF Experience:**Description of Non-SNF Experience:****Funded Development:****Operating Environment:****R and D Costs:****Procurement Costs:****In-Cell Space:****Out-Cell Space:****O and M Personnel:****R and D Schedule:****Deployment Schedule:****Measurable Configurations:****Additional Information:**

In search of funding.

Dry Cell.

\$200K to \$1M

<\$200K

<10 sq. ft.

10 to 50 sq. ft.

<1 FTE

<1 yr

1 to 2 yrs

Bare Fuel and Canisters

R & D cost would cover most of the procurement costs as well.

This is a passive system.

SNF Property # 1**Performance Goal:****Meets Performance Goal:****Phenomena Measured:**

Pu-239 content (weight % & g) (Post-Irradiation)

Key Property: +/- 70%

Yes

Gross neutron count rate from Pu and Cm. Confirms relationship between reactor records and neutron count rates for a collection of subassemblies.

Additional Information Required:

	BOL Enrichment
Last Date of Irradiation	BOL Fissile Content
Other (Identified in Property Measurement Comments)	

Measurement Uncertainty:**Measurement Duration:****Sensitivity to Measurement Duration:****Calibration Standards Required:****Property Measurement Comments:**

10%

60 min.

Uncertainty is improved by increasing measurement duration.

<10 Standards.

Standard technique used with LANL "Fork" detector.

Requires knowledge of fuel geometry and material properties to calculate correction factors for self-absorption, etc.

SNF Property # 2**Performance Goal:****Meets Performance Goal:****Phenomena Measured:**

Total Pu content (post-irradiation) (g)

+/- 70%

Yes

Gross neutron count rate from Pu and Cm. Confirms relationship between reactor records and neutron count rates for a collection of subassemblies.

Additional Information Required:

	BOL Enrichment
Last Date of Irradiation	BOL Fissile Content
Other (Identified in Property Measurement Comments)	

Measurement Uncertainty:

10%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

Standard technique used with LANL "Fork" detector.

Requires knowledge of fuel geometry and material properties to calculate correction factors for self-absorption, etc.

SNF Property # 3**Performance Goal:****Meets Performance Goal:****Phenomena Measured:**

Burnup (MWD/MTHM)

+/- Factor of 3 to 10

Yes

Gross neutron count rate from Pu and Cm. Confirms relationship between reactor records and neutron count rates for a collection of subassemblies.

Additional Information Required:

	BOL Enrichment
Last Date of Irradiation	BOL Fissile Content
Other (Identified in Property Measurement Comments)	

Measurement Uncertainty:

10%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

Standard technique used with LANL "Fork" detector.

Requires knowledge of fuel geometry and material properties to calculate correction factors for self-absorption, etc.

Limiting SNF Attribute # 1 No Limitation**Attribute Value:** No Limitation**Limiting Attribute Comment:**

SNF Property # 4	Gross gamma flux
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	Gross gamma-ray count rate
Additional Information Required:	None

Measurement Uncertainty:	10%
Measurement Duration:	1 min.
Sensitivity to Measurement Duration:	Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Requires knowledge of fuel geometry and material properties to calculate correction factors for self-absorption, etc.

Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	

SNF Property # 5	Gross neutron flux
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	Gross neutron count rate
Additional Information Required:	None

Measurement Uncertainty:	10%
Measurement Duration:	1 min.
Sensitivity to Measurement Duration:	Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	

Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	

SNF Property # 6

Performance Goal:

Meets Performance Goal:

Phenomena Measured:

Pu-238 & Pu-240 content (weight %) (Post-Irradiation)

No specific limit at this time.

Yes

Gross neutron count rate from Pu and Cm. Confirms relationship between reactor records and neutron count rates for a collection of subassemblies.

Additional Information Required:

	BOL Enrichment
Last Date of Irradiation	BOL Fissile Content
	Other (Identified in Property Measurement Comments)

Measurement Uncertainty:

10%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

Standard technique used with LANL "Fork" detector.

Requires knowledge of fuel geometry and material properties to calculate correction factors for self-absorption, etc.

System Report

System Name:**Description:****Shielded Measurement System Phase 2**

Combines gross gamma-ray, gross neutron, gamma-ray spectroscopy, and neutron coincidence measurements within a shielded enclosure to allow measurement of items without removing them from a hot cell. This is an active NDA system.

SNF Experience:**Description of SNF Experience:**

Proof of Principle.

Proof of principle accomplished for gross neutron counting in similar shielded geometry.

Non-SNF Experience:**Description of Non-SNF Experience:**

None.

Similar techniques have been used to measure non-irradiated plutonium in the past.

Funded Development:

In search of funding.

Operating Environment:

Dry Cell.

R and D Costs:

\$200K to \$1M

Procurement Costs:

<\$200K

In-Cell Space:

<10 sq. ft.

Out-Cell Space:

10 to 50 sq. ft.

O and M Personnel:

<1 FTE

R and D Schedule:

1 to 2 yrs

Deployment Schedule:

2 to 4 yrs

Measurable Configurations:

Bare Fuel and Canisters

Additional Information:

R & D cost would cover most of the procurement costs as well.

SNF Property # 1

Pu-239 content (weight % & g) (Post-Irradiation)

Performance Goal:

Key Property: +/- 70%

Meets Performance Goal:

Yes

Phenomena Measured:

Gross neutron rate, gamma-ray spectrum, and active neutron measurement.

Additional Information Required:

Last Date of Irradiation

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:

10%

Measurement Duration:

60 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

Information on irradiation history is also required.

SNF Property # 2	Total Fissile Material in Disposable Canister
Performance Goal:	Key Property: +/- 70%
Meets Performance Goal:	Yes
Phenomena Measured:	Coincident neutron response to neutron interrogation.
Additional Information Required:	None
Measurement Uncertainty:	20%
Measurement Duration:	60 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Requires knowledge of fuel geometry and material properties to calculate correction factors for self-absorption, etc.
Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	
SNF Property # 3	Total Pu content (post-irradiation) (g)
Performance Goal:	+/- 70%
Meets Performance Goal:	Yes
Phenomena Measured:	Gross neutron rate, gamma-ray spectrum, and active neutron measurement.
Additional Information Required:	Last Date of Irradiation Other (Identified in Property Measurement Comments)
Measurement Uncertainty:	10%
Measurement Duration:	60 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Information on irradiation history is also required.
SNF Property # 4	Activation products (Ci)
Performance Goal:	+/- Factor of 3 to 10
Meets Performance Goal:	Yes
Phenomena Measured:	Gamma-ray spectrum from activation products
Additional Information Required:	None
Measurement Uncertainty:	10%
Measurement Duration:	5 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Requires knowledge of fuel geometry and material properties to calculate correction factors for self-absorption, etc.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 5 Burnup (MWD/MTHM)
Performance Goal: +/- Factor of 3 to 10
Meets Performance Goal: Yes
Phenomena Measured: Gross neutron count and/or isotope ratio measurement from gamma-ray spectrum

Additional Information Required: BOL Enrichment
BOL Fissile Content
Other (Identified in Property Measurement Comments)
Reactor Design and Neutronics

Measurement Uncertainty: 10%
Measurement Duration: 60 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: Gross neutron count requires reactor records and provides only correlation between records and a series of measured items.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 6 Gross gamma flux
Performance Goal: No specific limit at this time.
Meets Performance Goal: Yes
Phenomena Measured: Gamma Flux
Additional Information Required: None

Measurement Uncertainty: 10%
Measurement Duration: 6 min.
Sensitivity to Measurement Duration: Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments:

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 7	Gross neutron flux
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	Neutron flux
Additional Information Required:	None
Measurement Uncertainty:	10%
Measurement Duration:	6 min.
Sensitivity to Measurement Duration:	Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	
Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	
SNF Property # 8	Pu-238 & Pu-240 content (weight %) (Post-Irradiation)
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	Gross neutron rate, gamma-ray spectrum, and active neutron measurement.
Additional Information Required:	Last Date of Irradiation Other (Identified in Property Measurement Comments)
Measurement Uncertainty:	10%
Measurement Duration:	60 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Information on irradiation history is also required.
SNF Property # 9	Ac227;Am241/2m/3;C14;Cl36;Cm244/5/6;Cs135;Nb93m/94;Ni59/63;Pa231;Pb210;Pd107;Pu242;Ra226/8;Se79;Sm151;Sn126;Th-229/230;Zr93 (Ci/package)
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	Gross neutron rate, gamma-ray spectrum, and active neutron measurement.
Additional Information Required:	None
Measurement Uncertainty:	10%
Measurement Duration:	60 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Information on irradiation history is also required.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

System Report

System Name:**Description:****SNF Digital Radiography Imaging System**

SRS's DR Imaging System uses an Iridium 192 radioisotope, high-density scintillating glass, and a cooled slow-scanned charge-coupled device camera to acquire radiographic images.

SNF Experience:**Description of SNF Experience:**

Proof of Principle.

Highly radioactive (>3000 REM/Hr) surface dose-rate canisters evaluated with this system during proof-of-principle tests. Outstanding radiographic images were acquired.

Non-SNF Experience:**Description of Non-SNF Experience:**

Field Deployed for Single SNF/Non-SNF.

SRS's DR Imaging Team has successfully deployed system's based on similar technology for imaging pinch welds, B-25 low-level waste boxes, 55 gallon mixed waste and TRU drums, and long-term storage containers.

Funded Development:

Presently funded to provide computer controlled systems for imaging pinch welds at SRS, highly radioactive canisters at ORNL, Actinide Packaging and Storage Facility SNM storage containers, and the welds on 55 gallon drums at SRS.

Operating Environment:**R and D Costs:****Procurement Costs:****In-Cell Space:****Out-Cell Space:****O and M Personnel:****R and D Schedule:****Deployment Schedule:****Measurable Configurations:****Additional Information:**

Underwater and Dry Cell.

<\$200K

\$200K to \$1M

<10 sq. ft.

10 to 50 sq. ft.

1 to 2 FTEs

<1 yr

<1 yr

Bare Fuel and Canisters

SRS's DR Imaging System has very few moving parts. It can be operated remotely with a single, fiber-optics cable. These systems are very robust and have very little (if any) downtime. This imaging systems lends itself to low-cost computed tomography imaging.

SNF Property # 1**Performance Goal:****Meets Performance Goal:****Phenomena Measured:**

Clad material (Zr, SS, etc.) and condition (Text)

No specific limit at this time.

Yes

Wall condition and thickness. Closure weld integrity. Possible internal pressurization.

Additional Information Required:

None

Measurement Uncertainty:**Measurement Duration:****Sensitivity to Measurement Duration:****Calibration Standards Required:****Property Measurement Comments:**

N.A. %

20 min.

Uncertainty is improved by increasing measurement duration.

<10 Standards.

The smaller the field of view, the better the resolution.

Limiting SNF Attribute # 1

No Limitation

Attribute Value:

No Limitation

Limiting Attribute Comment:

SNF Property # 2	Condition of fuel (intact, failed clad, degraded, etc.) (Text)
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	
Additional Information Required:	None

Measurement Uncertainty:	N.A. %
Measurement Duration:	20 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	
Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	

SNF Property # 3	Fuel compound (UO ₂ , U-metal, etc.) (Text)
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	
Additional Information Required:	None

Measurement Uncertainty:	N.A. %
Measurement Duration:	20 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	
Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	

SNF Property # 4	Fuel dimensions (pellet diameter, clad ID & OD, plate thickness, etc.) (cm)
Performance Goal:	+/- 0.254 cm w; +/- 2.54 cm l
Meets Performance Goal:	Yes
Phenomena Measured:	
Additional Information Required:	None

Measurement Uncertainty:	%
Measurement Duration:	20 min.
Sensitivity to Measurement Duration:	Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 5 Fuel rod pitch or plate spacing (cm)
Performance Goal: No specific limit at this time.
Meets Performance Goal: Yes
Phenomena Measured:
Additional Information Required: None

Measurement Uncertainty: %
Measurement Duration: 20 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments:

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 6 Free Liquids in Canistered SNF
Performance Goal: 0.2 kg to 1.3 kg total water
Meets Performance Goal: Yes
Phenomena Measured:
Additional Information Required: None

Measurement Uncertainty: %
Measurement Duration: 20 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments:

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 7	Number of SNF assemblies/items (Integer)
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	
Additional Information Required:	None
Measurement Uncertainty:	N.A.%
Measurement Duration:	20 min.
Sensitivity to Measurement Duration:	Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	
Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	
SNF Property # 8	Requirements that canisters be sealed
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	
Additional Information Required:	None
Measurement Uncertainty:	N.A.%
Measurement Duration:	20 min.
Sensitivity to Measurement Duration:	Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	
Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	
SNF Property # 9	Type of SNF assembly/item - Descriptive name (Text)
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	
Additional Information Required:	None
Measurement Uncertainty:	N.A.%
Measurement Duration:	20 min.
Sensitivity to Measurement Duration:	Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

System Report

System Name:	Solid State SNF Radiographic Imaging System
Description:	This system uses iridium 192 and Omega International Technology's (OIT) solid state imaging detectors to acquire radiographic images.
SNF Experience:	None.
Description of SNF Experience:	No experience with SNF.
Non-SNF Experience:	Field Deployed for Single SNF/Non-SNF.
Description of Non-SNF Experience:	The OIT detectors are extremely efficient. The Actinide Packaging and Storage Facility laser closure weld would not be radiographically inspectable without the use of these detectors. Prototype in use for more than one year.
Funded Development:	Actinide Packaging and Storage Facility storage container closure weld imaging. (Very successful!)
Operating Environment:	Underwater and Dry Cell.
R and D Costs:	<\$200K
Procurement Costs:	\$200K to \$1M
In-Cell Space:	<10 sq. ft.
Out-Cell Space:	<10 sq. ft.
O and M Personnel:	1 to 2 FTEs
R and D Schedule:	<1 yr
Deployment Schedule:	<1 yr
Measurable Configurations:	Bare Fuel and Canisters
Additional Information:	OIT's solid state detectors are so efficient that high-density fuel elements (such as N Reactor SNF) could be radiographically evaluated. This technology lends itself to computed tomography.
SNF Property # 1	Clad material (Zr, SS, etc.) and condition (Text)
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	Wall condition and thickness. Closure weld integrity. Possible internal pressurization.
Additional Information Required:	None
Measurement Uncertainty:	N.A. %
Measurement Duration:	20 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	The smaller the field of view, the better the resolution.
Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	

SNF Property # 2	Condition of fuel (intact, failed clad, degraded, etc.) (Text)
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	
Additional Information Required:	None

Measurement Uncertainty:	N.A. %
Measurement Duration:	20 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	
Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	

SNF Property # 3	Fuel compound (UO ₂ , U-metal, etc.) (Text)
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	
Additional Information Required:	None

Measurement Uncertainty:	N.A. %
Measurement Duration:	20 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	
Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	

SNF Property # 4	Fuel dimensions (pellet diameter, clad ID & OD, plate thickness, etc.) (cm)
Performance Goal:	+/- 0.254 cm w; +/- 2.54 cm l
Meets Performance Goal:	Yes
Phenomena Measured:	
Additional Information Required:	None

Measurement Uncertainty:	%
Measurement Duration:	20 min.
Sensitivity to Measurement Duration:	Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 5 Fuel rod pitch or plate spacing (cm)
Performance Goal: No specific limit at this time.
Meets Performance Goal: Yes
Phenomena Measured:
Additional Information Required: None

Measurement Uncertainty: %
Measurement Duration: 20 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments:

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 6 Free Liquids in Canistered SNF
Performance Goal: 0.2 kg to 1.3 kg total water
Meets Performance Goal: Yes
Phenomena Measured:
Additional Information Required: None

Measurement Uncertainty: %
Measurement Duration: 20 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments:

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 7	Number of SNF assemblies/items (Integer)
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	
Additional Information Required:	None
Measurement Uncertainty:	N.A.%
Measurement Duration:	20 min.
Sensitivity to Measurement Duration:	Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	
Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	
SNF Property # 8	Requirements that canisters be sealed
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	
Additional Information Required:	None
Measurement Uncertainty:	N.A.%
Measurement Duration:	20 min.
Sensitivity to Measurement Duration:	Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	
Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	
SNF Property # 9	Type of SNF assembly/item - Descriptive name (Text)
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	
Additional Information Required:	None
Measurement Uncertainty:	N.A.%
Measurement Duration:	20 min.
Sensitivity to Measurement Duration:	Uncertainty is not improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

System Report

System Name:**Description:****Storage Canister Gas Activation**

This system was proposed (but never built due to a change in requirements) to monitor the inventory of stored spent N-Reactor fuel nonintrusively. The system would measure the neutron activation products in a cover gas in a spent fuel storage canister. The continual presence of the same quantity of activation products would indicate the continued presence of the same quantity of neutron emitting isotopes. Combined with measuring the differential gas pressure and temperature, which would verify the same fuel volume and heat load, the inventory of the spent fuel could be verified without opening the storage canister. The only data provided is verification of the continued presence of inventoried fuel. The system would be suitable for any type of fuel in a closed container.

SNF Experience:**Description of SNF Experience:****Non-SNF Experience:****Description of Non-SNF Experience:****Funded Development:****Operating Environment:****R and D Costs:****Procurement Costs:****In-Cell Space:****Out-Cell Space:****O and M Personnel:****R and D Schedule:****Deployment Schedule:****Measurable Configurations:****Additional Information:**

Proof of Principle.

Proof of Principle.

Dry Cell.

\$200K to \$1M

\$200K to \$1M

10 to 50 sq. ft.

10 to 50 sq. ft.

<1 FTE

1 to 2 yrs

1 to 2 yrs

Canister

SNF Property # 1**Performance Goal:****Meets Performance Goal:****Phenomena Measured:****Additional Information Required:**

Disposable Multi-Element Canister Thermal Output

No specific limit at this time.

Yes

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:**Measurement Duration:****Sensitivity to Measurement Duration:****Calibration Standards Required:****Property Measurement Comments:**

10%

15 min.

Uncertainty is not improved by increasing measurement duration.

<10 Standards.

Each type of canister must be calibrated individually.

Each canister must have a mechanism (e.g., valve) for drawing a sample.

Requires information about the canister and its thermal environment.

SNF Property # 2**Performance Goal:****Meets Performance Goal:****Phenomena Measured:****Additional Information Required:**

Gross neutron flux

No specific limit at this time.

Yes

None

Measurement Uncertainty:**Measurement Duration:****Sensitivity to Measurement Duration:****Calibration Standards Required:****Property Measurement Comments:**

10%

15 min.

Uncertainty is not improved by increasing measurement duration.

<10 Standards.

Each type of canister must be calibrated individually.

Each canister must have a mechanism (e.g., valve) for drawing a sample.

SNF Property # 3**Performance Goal:****Meets Performance Goal:****Phenomena Measured:****Additional Information Required:**

Total Thermal Output for Disposable Canisters

No specific limit at this time.

Yes

None

Measurement Uncertainty:**Measurement Duration:****Sensitivity to Measurement Duration:****Calibration Standards Required:****Property Measurement Comments:**

10%

15 min.

Uncertainty is not improved by increasing measurement duration.

<10 Standards.

Each type of canister must be calibrated individually.

Each canister must have a mechanism (e.g., valve) for drawing a sample.

System Report

System Name:

Description:

Synchronous Active Neutron Detection

The SAND system is an active neutron assay system that measures prompt (rather than delayed) neutrons. In this context, it is similar to most active, prompt neutron assay systems, such as the first generation differential die-away (DDA) machine. The SAND design directly addresses the problem of high curium concentration spent fuel assay. Spent fuel samples with high curium concentration, namely those with low initial enrichment and high burnup, have a large neutron background. The neutron background can effectively shield the neutron signal induced by the active interrogation and can mask and accurate assay. The SAND system uses a programmable neutron generator operating at a 50% duty factor and neutron counting electronics that allow scaling in time to achieve an improved signal to noise ratio over conventional, gated systems. The SAND system achieves a factor of four improvement in variance over conventional, DDA-based, prompt active neutron assay systems. The SAND system can also be extended to make a dual prompt/delayed neutron measurement. The combined prompt/delayed measurement would allow direct assay of both the fissile content and the plutonium concentration, without making inferences using burnup calculations. The SAND system is effective on the same materials as either the RRFC, the Collar, or the Shuffler. However, it extends the capabilities of these machines to materials with a higher curium content (i.e., with lower initial enrichment or higher burnup). Notably, the SAND concept can be combined with other approaches, such as the high fluence neutron source or the combined prompt/delayed active neutron measurement.

SNF Experience:

Description of SNF Experience:

Non-SNF Experience:

Description of Non-SNF Experience:

Funded Development:

Operating Environment:

R and D Costs:

Procurement Costs:

In-Cell Space:

Out-Cell Space:

O and M Personnel:

R and D Schedule:

Deployment Schedule:

Measurable Configurations:

Additional Information:

Laboratory Development.

Tested with fresh fuel that had sources added to simulate spent fuel.

None.

This system was funded under LDRD.

Dry Cell.

\$1M to \$5M

\$200K to \$1M

10 to 50 sq. ft.

10 to 50 sq. ft.

1 to 2 FTEs

<1 yr

1 to 2 yrs

Bare Fuel and Canisters

This system performance will depend entirely on the strength of the neutron source. The values selected here apply to a 10^8 source. Stronger sources would scale linearly.

SNF Property # 1	Pu-239 content (weight % & g) (Post-Irradiation)
Performance Goal:	Key Property: +/- 70%
Meets Performance Goal:	Yes
Phenomena Measured:	Measures fissile content and k_eff. The Pu-239 content must then be inferred from geometry, burnup, and isotopics.

Additional Information Required:

Burnup	Other (Identified in Property Measurement Comments)
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Measurement Uncertainty:	50%
Measurement Duration:	30 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Isotopics is required through gamma spectroscopy.

Limiting SNF Attribute # 1 Fuel unit poison material

Attribute Value:	Boron
Attribute Value:	Cadmium
Attribute Value:	Erbium
Attribute Value:	Gadolinium

Limiting Attribute Comment:

Limiting SNF Attribute # 2 Gross neutron radiation (based on PWR assembly)

Attribute Value:	1E+06 to 1E+08 neutron/assy/sec
Attribute Value:	>1E+08 neutron/assy/sec

Limiting Attribute Comment:

SNF Property # 2	Total Fissile Material in Disposable Canister
Performance Goal:	Key Property: +/- 70%
Meets Performance Goal:	Yes
Phenomena Measured:	k_eff or the fissile response
Additional Information Required:	None

Measurement Uncertainty:	50%
Measurement Duration:	30 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	

Limiting SNF Attribute # 1 No Limitation

Attribute Value: No Limitation

Limiting Attribute Comment:

SNF Property # 3 U-233 content, (Post-irradiation) (weight % & g)
Performance Goal: Key Property: +/- 70%
Meets Performance Goal: Yes
Phenomena Measured: Fissile material or k_eff.
Additional Information Required:

Other (Identified in Property Measurement Comments)

Measurement Uncertainty: 50%
Measurement Duration: 30 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: Isotopics is required through gamma spectroscopy.

Limiting SNF Attribute # 1 Fuel unit poison material
Attribute Value: Boron
Attribute Value: Cadmium
Attribute Value: Erbium
Attribute Value: Gadolinium

Limiting Attribute Comment:

Limiting SNF Attribute # 2 Gross neutron radiation (based on PWR assembly)
Attribute Value: 1E+06 to 1E+08 neutron/assy/sec
Attribute Value: >1E+08 neutron/assy/sec

Limiting Attribute Comment:

SNF Property # 4 U-235 content, (Post-irradiation) (weight % & g)
Performance Goal: Key Property: +/- 70%
Meets Performance Goal: Yes
Phenomena Measured: Fissile material or k_eff.
Additional Information Required:

Other (Identified in Property Measurement Comments)

Measurement Uncertainty: 50%
Measurement Duration: 30 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: Isotopics is required through gamma spectroscopy.

Limiting SNF Attribute # 1 Fuel unit poison material
Attribute Value: Boron
Attribute Value: Cadmium
Attribute Value: Erbium
Attribute Value: Gadolinium

Limiting Attribute Comment:

Limiting SNF Attribute # 2 Gross neutron radiation (based on PWR assembly)
Attribute Value: 1E+06 to 1E+08 neutron/assy/sec
Attribute Value: >1E+08 neutron/assy/sec

Limiting Attribute Comment:

SNF Property # 5**Performance Goal:****Meets Performance Goal:****Phenomena Measured:**

Total Pu content (post-irradiation) (g)

+/- 70%

Yes

Measures fissile content and k_{eff}. The Pu-239 content must then be inferred from geometry, burnup, and isotopics.**Additional Information Required:**

Burnup

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:

50%

Measurement Duration:

30 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

Isotopics is required through gamma spectroscopy.

Limiting SNF Attribute # 1

Fuel unit poison material

Attribute Value: Boron**Attribute Value:** Cadmium**Attribute Value:** Erbium**Attribute Value:** Gadolinium**Limiting Attribute Comment:****Limiting SNF Attribute # 2**

Gross neutron radiation (based on PWR assembly)

Attribute Value: 1E+06 to 1E+08 neutron/assy/sec**Attribute Value:** >1E+08 neutron/assy/sec**Limiting Attribute Comment:****SNF Property # 6****Performance Goal:****Meets Performance Goal:****Phenomena Measured:**

Burnup (MWD/MTHM)

+/- Factor of 3 to 10

Yes

Measures fissile content and k_{eff}. The Pu-239 content must then be inferred from geometry, burnup, and isotopics.**Additional Information Required:**

Burnup

Other (Identified in Property Measurement Comments)

Measurement Uncertainty:

50%

Measurement Duration:

30 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

Isotopics is required through gamma spectroscopy.

Limiting SNF Attribute # 1 Fuel unit poison material

Attribute Value: Boron

Attribute Value: Cadmium

Attribute Value: Erbium

Attribute Value: Gadolinium

Limiting Attribute Comment:

Limiting SNF Attribute # 2 Gross neutron radiation (based on PWR assembly)

Attribute Value: 1E+06 to 1E+08 neutron/assy/sec

Attribute Value: >1E+08 neutron/assy/sec

Limiting Attribute Comment:

SNF Property # 7

Gross neutron flux

Performance Goal: No specific limit at this time.

Meets Performance Goal: Yes

Phenomena Measured:

Additional Information Required: None

Measurement Uncertainty: 10%

Measurement Duration: 5 min.

Sensitivity to Measurement Duration: Uncertainty is not improved by increasing measurement duration.

Calibration Standards Required: <10 Standards.

Property Measurement Comments:

Limiting SNF Attribute # 1 No Limitation

Attribute Value: No Limitation

Limiting Attribute Comment:

SNF Property # 8

Pu-238 & Pu-240 content (weight %) (Post-Irradiation)

Performance Goal: No specific limit at this time.

Meets Performance Goal: Yes

Phenomena Measured: Measures fissile content and k_eff. The Pu-239 content must then be inferred from geometry, burnup, and isotopics.

Additional Information Required:

Burnup

Other (Identified in Property Measurement Comments)

Measurement Uncertainty: 50%

Measurement Duration: 30 min.

Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.

Calibration Standards Required: <10 Standards.

Property Measurement Comments: Isotopics is required through gamma spectroscopy.

Limiting SNF Attribute # 1 Fuel unit poison material

Attribute Value: Boron

Attribute Value: Cadmium

Attribute Value: Erbium

Attribute Value: Gadolinium

Limiting Attribute Comment:

Limiting SNF Attribute # 2 Gross neutron radiation (based on PWR assembly)

Attribute Value: 1E+06 to 1E+08 neutron/assy/sec

Attribute Value: >1E+08 neutron/assy/sec

Limiting Attribute Comment:

SNF Property # 9

k-eff

Performance Goal: < 0.95 after bias/uncertainty

Meets Performance Goal: Yes

Phenomena Measured: Fissile material or k_eff.

Additional Information Required: None

Measurement Uncertainty: 20%

Measurement Duration: 30 min.

Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.

Calibration Standards Required: <10 Standards.

Property Measurement Comments:

Limiting SNF Attribute # 1 Fuel unit poison material

Attribute Value: Boron

Attribute Value: Cadmium

Attribute Value: Erbium

Attribute Value: Gadolinium

Limiting Attribute Comment:

Limiting SNF Attribute # 2 Gross neutron radiation (based on PWR assembly)

Attribute Value: 1E+06 to 1E+08 neutron/assy/sec

Attribute Value: >1E+08 neutron/assy/sec

Limiting Attribute Comment:

System Report

System Name:**Description:****Thermal and Epithermal Neutron Radiography System**

Thermal and epithermal neutrons are transmitted through a sample to produce a radiograph of the sample

SNF Experience:

Field Deployed for Multiple SNF/Non-SNF.

Description of SNF Experience:

Field Deployed for Multiple SNF/Non-SNF.

Non-SNF Experience:**Description of Non-SNF Experience:****Funded Development:**

Funding in place

Operating Environment:

Dry Cell.

R and D Costs:

<\$200K

Procurement Costs:

<\$200K

In-Cell Space:

10 to 50 sq. ft.

Out-Cell Space:

10 to 50 sq. ft.

O and M Personnel:

> 2 FTEs

R and D Schedule:

None

Deployment Schedule:

<1 yr

Measurable Configurations:

Bare Fuel and Canisters

Additional Information:

This system has been used for spent fuel examinations for many years at ANLW.

SNF Property # 1**Performance Goal:**

Concentration and total masses of neutron absorbers (g/m³ & g)

Meets Performance Goal:

No specific limit at this time.

Phenomena Measured:

Yes

Additional Information Required:

Neutron transmission through the sample

None

Measurement Uncertainty:

10%

Measurement Duration:

20 min.

Sensitivity to Measurement Duration:

Uncertainty is improved by increasing measurement duration.

Calibration Standards Required:

<10 Standards.

Property Measurement Comments:

Current system is limited to 7 x 17 inch radiographs. Multiple radiographs may be required for larger fuels.

Limiting SNF Attribute # 1 No Limitation

Attribute Value: No Limitation

Limiting Attribute Comment:

SNF Property # 2	Condition of fuel (intact, failed clad, degraded, etc.) (Text)
Performance Goal:	No specific limit at this time.
Meets Performance Goal:	Yes
Phenomena Measured:	Neutron transmission through the sample
Additional Information Required:	None
Measurement Uncertainty:	N.A. %
Measurement Duration:	20 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Current system is limited to 7 x 17 inch radiographs. Multiple radiographs may be required for larger fuels.
Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	
SNF Property # 3	Fuel dimensions (pellet diameter, clad ID & OD, plate thickness, etc.) (cm)
Performance Goal:	+/- 0.254 cm w; +/- 2.54 cm l
Meets Performance Goal:	Yes
Phenomena Measured:	Neutron transmission through the sample
Additional Information Required:	None
Measurement Uncertainty:	%
Measurement Duration:	20 min.
Sensitivity to Measurement Duration:	Uncertainty is improved by increasing measurement duration.
Calibration Standards Required:	<10 Standards.
Property Measurement Comments:	Current system is limited to 7 x 17 inch radiographs. Multiple radiographs may be required for larger fuels.
Limiting SNF Attribute # 1	No Limitation
Attribute Value:	No Limitation
Limiting Attribute Comment:	

SNF Property # 4
Performance Goal: Fuel rod pitch or plate spacing (cm)
Meets Performance Goal: No specific limit at this time.
Phenomena Measured: Yes
Additional Information Required: Neutron transmission through the sample
None

Measurement Uncertainty: %
Measurement Duration: 20 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: Current system is limited to 7 x 17 inch radiographs. Multiple radiographs may be required for larger fuels.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 5
Performance Goal: Identification of control components integral to fuel assembly (Text)
Meets Performance Goal: No specific limit at this time.
Phenomena Measured: Yes
Additional Information Required: Neutron transmission through the sample
None

Measurement Uncertainty: %
Measurement Duration: 20 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: Current system is limited to 7 x 17 inch radiographs. Multiple radiographs may be required for larger fuels.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 6
Performance Goal: Free Liquids in Canistered SNF
Meets Performance Goal: 0.2 kg to 1.3 kg total water
Phenomena Measured: Yes
Additional Information Required: Neutron transmission through the sample
None

Measurement Uncertainty: %
Measurement Duration: 20 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: Current system is limited to 7 x 17 inch radiographs. Multiple radiographs may be required for larger fuels.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment:

SNF Property # 7
Performance Goal: Type of SNF assembly/item - Descriptive name (Text)
Meets Performance Goal: No specific limit at this time.
Phenomena Measured: Yes
Additional Information Required: Neutron transmission through the sample
None

Measurement Uncertainty: N.A.%
Measurement Duration: 20 min.
Sensitivity to Measurement Duration: Uncertainty is improved by increasing measurement duration.
Calibration Standards Required: <10 Standards.
Property Measurement Comments: Current system is limited to 7 x 17 inch radiographs. Multiple radiographs may be required for larger fuels.

Limiting SNF Attribute # 1 No Limitation
Attribute Value: No Limitation
Limiting Attribute Comment: